FINAL REPORT

Demonstration & Testing of an EER Optimizer System for DX Air-conditioners

ESTCP Project EW-201338

JULY 2017

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EER Optimizer® is a versatile diagnostic and control technology that measures the Energy Efficiency Ratio (EER) of operating DX air-conditioner systems and provides a basis for optimizing energy use by measuring real-time, in-situ operational efficiency, which is not available with existing technology. The technology provides web monitoring & reporting of EER, IEER, Tons Capacity and detected faults such as low refrigerant, stuck TXV, restricted airflow, broken economizer and fouled coil, viewable at EERoptimizer.com The portable unit is web connected for remote technical assistance, storing readings on a cloud server for later retrieval and analysis, and to support evaluation of historical trends, reporting, and documentation.

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Bubble Fraction Sensor, Heating, Ventilation, and Air Conditioning, Compressor Contactor, Condenser Fan, Discharge Solenoid, Discharge Temperature Sensor, Evaporator Fan, High Pressure Sensor, High Temperature Sensor, Low Pressure Sensor, Programmable Logic Controller, Refrigerant Flow Sensor

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ACRONYMS AND ABBREVIATIONS

AHRI	American Heating & Refrigeration Institute
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigeration & Air conditioning Engineers
BLCC	Building Life Cycle Cost software
BFS	Bubble Fraction Sensor
C	Compressor Contactor
CCAFS	Cape Canaveral Air Force Station at Patrick Air Force Base
CF	Condenser Fan
CS	Charge Solenoid
CSV	Comma Separated Values
CTS	Condenser Temperature Sensor
DoD	Department of Defense
DOE	U.S. Department of Energy
DS	Discharge Solenoid
DTS	Discharge Temperature Sensor
DX	Direct Expansion as applied to refrigerant in air-conditioning equipment
ECO	Energy Conservation Opportunity
ECU	Environmental Control Unit
EER	Energy Efficiency Ratio, the ratio of cooling provided to power consumed in Btuh/ Watt
EF	Evaporator Fan
EMCS	Energy Management & Control System
ESCO	Energy Service Company
ESTCP	Environmental Security Technology Certification Program
FEMP	Federal Energy Management Program
FLEOH	Full Load Equivalent Operating Hours
GPM	Gallons per Minute
HPS	High Pressure Sensor
HTS	High Temperature Sensor
HVAC	Heating, Ventilation, and Air Conditioning
IEER	Integrated Energy Efficiency Ratio
in-WC	Inches water column
kW	kilo-Watts, 1000 Watts
LPS	Low Pressure Sensor

LTS	Low Temperature Sensor
MA	milli-Amps
MCAS	Marine Corps Air Station
MV	milli-Volts
NOTU	Naval Ordnance Test Unit
OEM	Original Equipment Manufacturer, such as Carrier, Trane, Lennox, York, McQuay
ORNL	Oak Ridge National Laboratory / U.S. Department of Energy
PBM	Performance-Based Maintenance
PCS	Power Current Sensor
PLC	Programmable Logic Controller
ppm	Parts Per Million
PSIG	Pounds per Square Inch Gauge
PVS	Power Voltage Sensor
RFS	Refrigerant Flow Sensor
RH	Relative Humidity
SBIR	Small Business Innovative Research
TMY	Typical Meteorological Year
VDC	Volts Direct Current
VTS	Vapor Temperature Sensor

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EXECUTIVE SUMMARY

EER Optimizer® is a versatile diagnostic and control technology that measures the Energy Efficiency Ratio (EER) of operating direct expansion (DX) air-conditioner and heat pump systems, which provides a basis for optimizing equipment energy use by measuring real-time, in-situ operational efficiency. EER Optimizer provides easy web access for monitoring & reporting of EER, IEER (Integrated EER), Tons Capacity and detects faults such as low refrigerant, stuck thermostatic expansion valve (TXV), restricted airflow, broken economizer and fouled coil, all viewable at EERoptimizer.com The portable version is web connected for remote technical assistance, storing readings on a cloud server for later retrieval and analysis, and to support evaluation of historical trends, reporting, and documentation.

Three demonstration sites provided a full range of conditions for the EER Optimizer technology to evaluate the flexibility and efficacy needed for the widely varying climates of U.S. Department of Defense (DoD) installations. The demonstrations included onboard controls installed on operating package air conditioners at sites in South Carolina, Florida, and California, as well as use of handheld EER Optimizer technology to demonstrate effectiveness when used as an operations & maintenance (O&M) tool by HVAC technicians.

The reduction in normalized air-conditioner energy usage averaged 28% among the three demonstration sites. Reduction at Fort Irwin was 30%, reduction at Marine Corps Air Station Beaufort (MCASB) was 24%, and reduction at Cape Canaveral Air Force Station (CCAFS) was 30%. All three units exhibited a significant increase in IEER and commensurate decrease in normalized energy use for a cooling season, relative to baseline IEER measurements. The average improvement in measured IEER was 19.7%. There is a wide variation in cost effectiveness across the three demonstration sites, and payback period ranged from 3.2 to 5.8 years. Larger air conditioners using more energy will provide shorter payback period. The portable EER Optimizer's fault detection & diagnostics provided energy savings averaging 22% over groups of 10 package air conditioners at each site. The equipment service needs indicated by the portable unit produced payback periods ranging from 0.4 to 1.1 years, with savings-to-investment ratio (SIR) ranging from 1.0 to 2.4 for the 30 packaged air-conditioners.

Overall, indoor air quality and thermal comfort were unchanged or improved, and temperature and humidity were more tightly controlled. There was reduction in the level and severity of unplanned and/or emergency repairs. The EER Optimizer system allowed project engineers to identify performance issues sooner and prevent more severe failures. Technicians using EER Optimizer stated that the remote fault detection & diagnostics feature is a key benefit for them. Overall, the occupant comfort perception survey responses were more positive for the test period than they were for the baseline period.

If DoD subsequently incorporates the results of this demonstration into policy, training, and Heating, Ventilation and Air Conditioning (HVAC) management and procurement standards, DoD could contribute significantly to addressing the potential for efficiency improvement in unitary HVAC equipment. Implementation of the technology is straightforward and cost is low enough to meet payback period and return on investment thresholds for Energy Saving Performance Contract (ESPC) and Utility Energy Saving Contract (UESC) funded projects.

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1.0 INTRODUCTION

Commercial unitary HVAC systems, or rooftop air conditioners, are used to cool over 60% of U.S. commercial floor area.[1] Military installations utilize unitary HVAC technology for space conditioning in buildings such as commissaries, schools, and theaters, and in environmental control units (ECUs) used for mobile operations. In addition, many public buildings, such as schools and libraries, employ rooftop air conditioners for cooling. Rooftop units are also available in heat pump models as an alternative to fuel gas or electric resistance heating.

Rooftop air-conditioner units (RTUs) have been identified as an excellent target for facility energy savings. The U.S. Department of Energy (DOE) teamed with American Society for Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) and the Retail Industry Leaders Association (RILA) to launch the Advanced RTU Campaign, started in May 2013. The Campaign *"…is a recognition and guidance program designed to encourage building owners and operators to take advantage of savings opportunities from high efficiency RTUs."*[2] The Campaign is based on the premise that both installed and new RTUs are excellent targets for improved energy efficiency and significant energy savings.

EER Optimizer® is a versatile diagnostic and control technology that measures the Energy Efficiency Ratio (EER) of operating RTUs and provides a basis for optimizing equipment energy use by directly measuring real-time, in-situ operational efficiency, a capability not available with competing technology. The patented [3] technology is analogous to the feedback control of central plant HVAC systems, which provide much more efficient cooling than RTUs. The demonstrations of the EER Optimizer technology included onboard controls installed on operating RTUs at three demonstration sites, as well as use of handheld EER Optimizer technology to demonstrate effectiveness when used as an operations & maintenance (O&M) tool by HVAC technicians. The demonstration project involved applying EER Optimizer technology, both onboard and handheld versions, at three DoD sites:

- Cape Canaveral Air Force Station, FL
- Marine Corps Air Station, Beaufort, SC
- Fort Irwin National Training Center, CA

The sites were selected to provide a range of operational conditions – temperature, relative humidity control, occupancy, etc. – to represent EER values that were experienced at a wide range of DoD sites. Demonstration of EER Optimizer at the demonstration sites began mid-summer 2015 and was completed at the end of the 2016 cooling season, giving a full cooling season for data collection and performance evaluation. Demonstration as both an onboard monitoring system and a portable instrument intended for field use provides a solid basis for EER Optimizer deployment at all DoD facilities where unitary DX equipment meets a significant cooling load.

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[1] U.S. Dept. of Energy, Better Buildings program, June 17, 2013 webinar, *Advanced RTU Campaign*, https://www4.eere.energy.gov/alliance/sites/default/files/uploaded-files/AdvancedRTUCampaignWebinar6-17-2013.pdf.

[2] Advanced RTU Campaign website - http://www.advancedrtu.org/

[3] US Patent numbers 6,427,454; 9,261,542; 9,574,810

1.1 BACKGROUND

Unitary DX split-system and package air conditioners and heat pumps are ubiquitous in DoD facilities and mobile units (ECUs). The large potential for improvement makes unitary systems an outstanding target for DoD facility energy efficiency upgrades. The energy efficiency of current unitary HVAC systems is much less than that of distributed chilled water systems and few cost-effective choices exist for increasing their energy efficiency. However, unitary systems are economically attractive because they can be installed wherever there is electric power, and don't require expensive chilled water piping or a cooling tower. Although DoD facilities utilize central chilled / hot water plants for large building heating and cooling, facilities such as commissaries, base exchanges, theaters and schools are often located remotely from chilled/hot water distribution piping and are therefore served by stand-alone unitary-DX HVAC systems.

Unitary HVAC systems are readily available in a range of capacities from 5 to 100 tons, have a relatively low first cost, and are easily serviced. However, even new best-in-class EER-14 commercial unitary[4] equipment does not give the 30% increase in efficiency over ASHRAE Standard 90.1 desired to meet Federal energy reduction goals. Current recommended energy efficiency specifications published by the Consortium for Energy Efficiency (CEEE) for new unitary air conditioning and heat pump systems[5] establish Energy Efficiency Ratios (EERs) of 10.3 to 11.7 and Integrated Energy Efficiency Ratios (IEER) of 11.4 to 12.9, depending on system capacity. Current models must meet the energy conservation standards specified in the Code of Federal Regulations[6] 10 CFR 431.97 of EER 9.8 to 11.2, depending on capacity. Upcoming Department of Energy requirements are a 13% increase in minimum efficiency (2018) and then a 28% (2023) increase[7]. However, the substantial base of installed unitary systems has an EER of 9.0 or less, dependent on system condition and maintenance history.[8]

EER is defined as the quantity of cooling provided per unit of electric power consumed, in units of 10^3BTU/hr per kW, sometimes notated as MBH/kW (MBtuH/kW), or simply Btuh per Watt. EER varies greatly with cooling load, refrigerant level, maintenance condition and airflow, age and wear & tear, among other factors. The energy efficiency of operating DX packaged and split cooling units is not directly and continuously measured, as with large campus chilled water HVAC plants, using current technology. Instead, energy engineers and service technicians use indirect indicators of equipment performance to subjectively assess efficiency. Technicians make adjustments to operating parameters according to manufacturer guidelines and standard field practice, which varies with technicians' level of experience. Current practice does not maximize the operating EER of unitary DX equipment, rather, the general goal is to avoid comfort complaints.

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[4] Commercial unitary equipment is understood to mean equipment over 5 tons capacity utilizing 3-phase electric power. EER-14 means an Energy Efficiency Rating of 14 Btuh of cooling per Watt of electric usage.
[5] The Consortium for Energy Efficiency (CEE), a North American non-profit organization with members including utilities, state energy offices, research organizations, and environmental groups, developed specifications for unitary systems in 2016 – see https://library.cee1.org/system/files/library/7559/CEE_ComACHP_UnitarySpec2016.pdf
[6] https://www.gpo.gov/fdsys/pkg/CFR-2012-title10-vol3/pdf/CFR-2012-title10-vol3-sec431-97.pdf
[7] https://www.ecfr.gov/cgi-bin/text-idx?SID=8a5b57743b0296e02d26b410d48df7d0&mc=true&node=se10.3.431_197&rgn=div8
[8] *Efficiency Maine* suggests assuming EER of 9.0 for systems 5-10 years old and 8.0 for systems 10-15 years old - http://www.efficiencymaine.com/pdfs/EM_SAW_Rooftop.pdf

1.2 OBJECTIVE OF THE DEMONSTRATION

The overarching performance objective is to increase energy efficiency and reduce energy consumption of the target unitary DoD air-conditioning equipment with an EER metering and feedback control technology. Project objectives are to validate the effectiveness and economics of EER Optimizer technology for:

- Maximizing the energy efficiency of a variety of DX cooling and heat pump systems, under operating conditions experienced at many DoD sites, as both a portable service instrument and an on-board metering & control technology.
- Identifying the need for curative maintenance or replacement of poorly performing units.
- Developing service procedures directly addressing energy efficiency performance.
- Developing a decision tree for repair- versus replacement-based energy economics.

The insights gained from the data collected can be incorporated into DoD best practices for O&M of unitary HVAC equipment, including incorporating the EER Optimizer technology to measure and adjust operating parameters such as refrigerant charge and fan speeds. DoD policy for O&M of this type equipment may be modified to include a target EER and guidelines for how frequently the equipment EER performance should be measured and optimized.

The results of the demonstration can be used to develop educational materials instructing DoD personnel and contractors who are responsible for O&M of unitary equipment in the use and value of EER Optimizer technology. These instructional materials can provide information on the use of EER Optimizer for ongoing monitoring and adjustment of all DoD unitary HVAC equipment. This data can be supplemented with information on how much EER can decline during normal equipment operation, while using currently accepted O&M practices.

If DoD subsequently incorporates the results of this demonstration into policy, training, and HVAC management and procurement standards, DoD could contribute significantly to addressing the potential for energy efficiency improvement in unitary HVAC equipment. While the US Department of Energy (DOE) has launched the Advanced RTU Campaign (http://www.advancedrtu.org/) to highlight the potential energy savings available in both new and retrofit applications of RTU technology, the results of this ESTCP demonstration can supplement DOE's effort by highlighting the value of continued RTU optimization through O&M practices. Given the DoD as a major RTU market, any DoD policy changes could have major influence on the national efforts to improve the energy efficiency of RTUs.

1.3 REGULATORY DRIVERS

- Installations Energy Instruction DODI 4170.11
- Energy Policy Act of 1992
- Energy Policy Act of 2005
- Executive Order 16393
- GSA 2010 Facilities Standards (P100)

- ASHRAE Energy Efficiency Standard 90.1
- ASHRAE Green Standard 189.1
- ASHRAE IAQ Standard 62.1 (2013 section 5.9)

2.0 TECHNOLOGY DESCRIPTION

EER Optimizer is a metering and feedback control technology embodied in two versions. The "onboard" version is intended to be permanently installed into a unitary system, such as a rooftop package unit, and can automatically change the refrigerant charge level, cooling coil temperature and airflow, and fan speeds to continuously maximize energy efficiency. The applicable capacity range of DX Air conditioners for this technology is 10 to 100 tons (120,000 to 1,200,000 Btuh). The "portable" hand-held version is intended to be carried by service technicians and energy engineers, who use the values displayed on the hand-held unit's touchscreen to tune refrigerant charge, fan speeds, and other parameters; to identify underperforming components such as a fouled condenser coil, to maximize energy efficiency, and to identify systems that are justified for replacement. EER Optimizer technology is well suited to DoD Performance Contracting efforts (ESPC and UESC) to reduce facility operating costs.

2.1 TECHNOLOGY OVERVIEW

EER Optimizer is a metering and feedback control technology that's embodied in two versions: onboard and portable.

1. The onboard efficiency controller version can be factory-installed in new equipment, as well as retrofitted to existing equipment to improve energy efficiency and cooling / dehumidification performance, reliability / uptime, and reduce energy costs.
2. The portable service tool version can be deployed as an enhancement of, in addition to or instead of standard refrigerant system analyzers, which virtually every service technician is adept at using. The technology can be the centerpiece of a performance-based maintenance (PBM) system whereby service actions are targeted according to return on investment.

The EER Optimizer obtains the EER measurement from the difference between the heat content of the refrigerant at the entrance and exit of the cooling coil, since increase in the heat content of the refrigerant must be balanced by an equal loss of heat from the air being cooled. This heat content difference is calculated from refrigerant enthalpies, which are calculated from measured refrigerant temperatures and pressures using pre-programmed property correlations. The property correlations are polynomial regression equations that allow relatively straightforward calculation of refrigerant density and heat content, rather than using traditional look up tables, directly from the temperature and pressure sensor signals.

The rate of heat transport is calculated from the refrigerant mass flow rate, which is calculated from the refrigerant volume flow rate and density, which in turn is calculated from sensed refrigerant velocity, temperature, and pressure using pre-programmed property correlations. The true root-mean-square (RMS) power demand is calculated by the technology by sampling the sensed input voltage and current sine waves. Finally, EER is calculated as the rate of heat transport divided by the power input, and provided as an Btuh per Watt display and/or as an analog signal output. The cooling being delivered and the power consumed is also be displayed.

2.1.1 Onboard Unit

The onboard controller processor output corresponds to EER, which is used to continuously adjust fan speeds, refrigerant level and flow, and any/all other operating parameters in an operating unit, as cooling load and operating conditions vary, to maximize actual operating energy efficiency. In contrast, the best competing technology can only select a high or low condenser fan speed based on temperature or pressure; and refrigerant level is fixed by the factory initially, and adjusted after installation by a service technician.

The EER Optimizer system uses a small onboard refrigerant receiver and two solenoid valves to shuttle refrigerant to/from the operating circuit via a high-pressure tap at the condenser coil and a low pressure tap at the evaporator coil. As needed to maximize EER, the controller transfers refrigerant from the condenser coil to the receiver by opening the high-pressure tap, and from receiver to the evaporator coil by opening the low pressure tap. In dual-circuit systems, a single receiver can be used to shuttle refrigerant between stages allowing both evaporator and/or condenser coil sections to be utilized for the first cooling stage, greatly increasing part-load heat transfer and energy efficiency.

The EER Optimizer outputs of EER (Btuh/Watt), cooling delivered (Tons) and power consumed (kW) as well as all other sensed and calculated values are provided as a Transmission Control Protocol/Internet Protocol (TCP/IP) text stream, and can optionally be provided as three industry-standard 0-5 volts direct current (VDC) or 4-20 milliamp (mA) analog outputs to a building automation system (BAS) or energy management and control system (EMCS) for monitoring, as well as displayed locally on a touch screen. The onboard controller uses a low cost inline flow meter element, threaded pressure sensors, and snap-on temperature and current sensors. The EER Optimizer controls RTU operational parameters locally, while the BAS / EMCS can control the active / inactive state of the controller via digital contact-closure inputs, along with alarms for out of range values.

2.1.2 Hand-held Unit

The hand-held portable service instrument enables a field service technician to directly evaluate the energy efficiency performance of any operating unit, adjust refrigerant level and fan speed, and perform other indicated service actions as needed to maximize IEER. The hand-held unit also enables faster and more accurate evaluation of potential energy savings from equipment replacement. The instrument uses familiar Schrader refrigerant pressure connections and clamp-on temperature sensors; a clamp-on refrigerant velocity sensor; and clamp-on electric voltage and current sensors. In all other respects, operation of the portable hand held version is similar to the refrigerant analyzers that service technicians currently use, requiring minimal training.

Figure 1. Photo of a Portable i-Optimze Unit, which Incorporates EER Optimzer Technology into a Handheld Diagnostic Tool and Easily Attachable / Detachable Sensors.

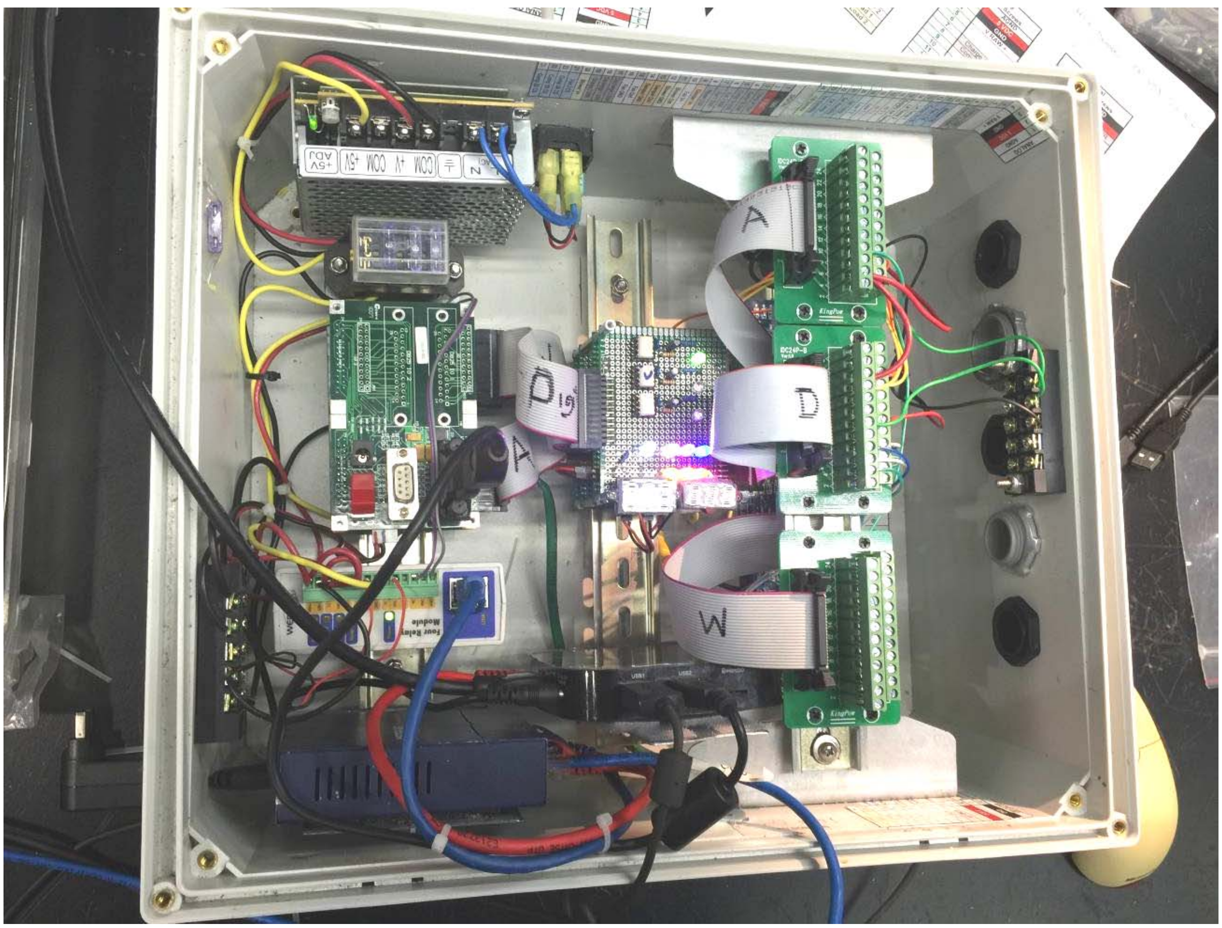


Figure 2. Photo of an EER Optimizer Control Unit Undergoing Quality Assurance Testing Before Installation.

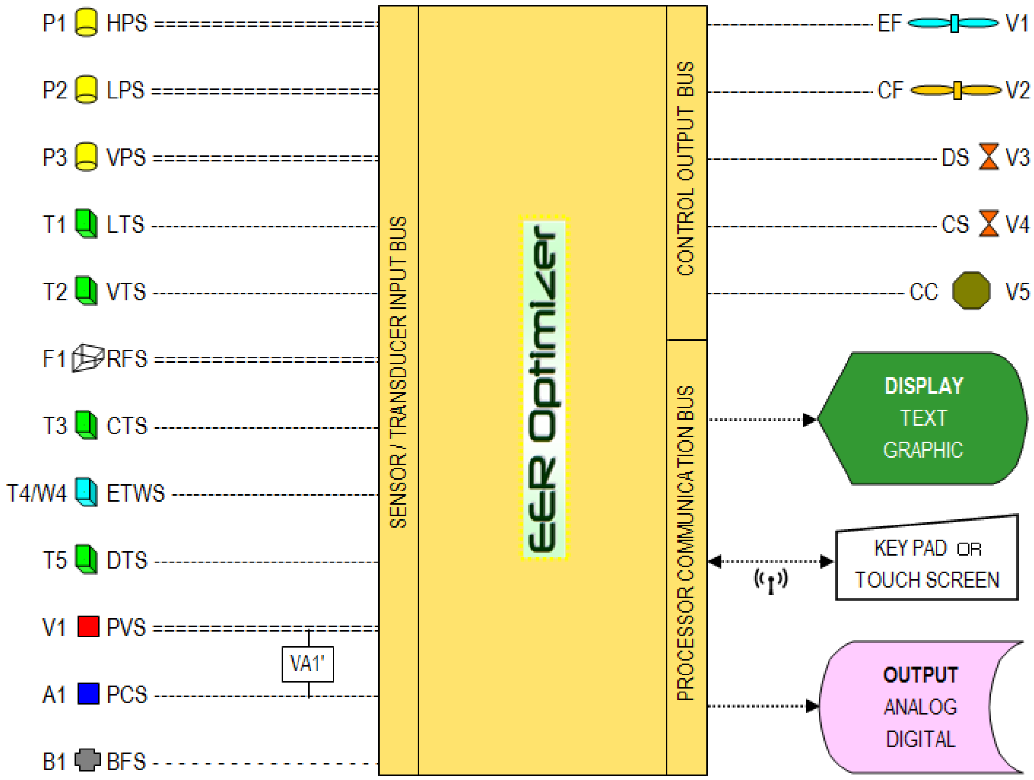


Figure 3. Schematic Representation of EER Optimizer Control System with Sensors at Left, Control Outputs at Top Right, and Communication IO at Bottom Right.

Pressure sensors are denoted by P, temperatures by T, voltages by V, and amperage by A.

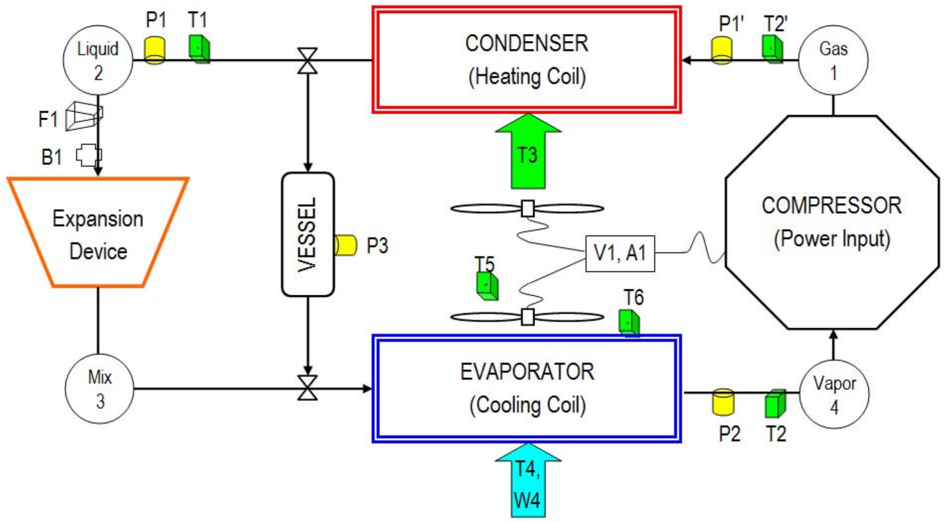


Figure 4. Schematic Diagram of Basic DX Refrigeration System Equipped with Charge / Discharge Receiver (vessel) Showing Locations of EER Optimizer Sensors.

2.2 TECHNOLOGY DEVELOPMENT

EER Optimizer is a well-developed, patented technology ready for widescale deployment and commercialization. Prerequisite technology development stages were successfully completed prior to demonstration. Refinement and testing of a bench scale prototype was completed in 2004. Development, lab testing and improvement of engineering prototypes under a Florida Energy Office / DOE project with assistance from Mastercool, Inc. were completed in 2005. Testing of on-board controller prototypes installed into a ClimateMaster 4-ton water-source heat pump and two Environs 3-ton dual-source heat pumps were concluded in 2009-10. On-going performance testing under typical field conditions quantitatively confirmed benefits predicted by theoretical analysis using the Oak Ridge National Lab (ORNL) Heat Pump Model, FrigoSim, RefSim software and National Institute of Standards and Technology (NIST) Cycle_D analysis. The engineering prototype was constructed using readily available components from instrument/control vendors (Fluke, Dynasonics, Mastercool, and American Sensor Technology).

Additional engineering analysis was completed to improve the accuracy of the refrigeration mass flow measurement to account for the presence of oil film on the tube inside surface when there are vapor bubbles. A DX air-conditioner compressor contains oil for lubrication, and inevitably some of that oil leaves the compressor and is carried throughout the system by the flowing refrigerant. Oil and liquid refrigerant are miscible so they exist as a homogenous solution, however, oil and vapor/gas refrigerant are two-phase. As refrigerant changes phase from liquid to vapor, the oil comes out of solution and tends to adhere to the tube wall because it is denser and more viscous. The oil film is carried along the tube wall by the flowing refrigerant. Since the oil moves at a significantly lower velocity than the refrigerant, the slower moving oil can potentially skew flow rate measurements. The resulting flow sensing signals are first conditioned by an analog filter, and statistical digital filtering is used to identify and compensate for the presence of refrigerant bubbles. This approach was found to work very well.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

EER Optimizer is a metering and feedback control technology that’s embodied in two versions: onboard and portable. There is no competing technology that continuously seeks the unique combination of operating parameters that minimizes electric usage per unit of cooling delivered. There is no competing technology that accurately measures the energy efficiency of an operating unit in the field, using the industry standard EER and IEER efficiency metrics.

The “onboard” version is intended to be permanently installed into a DX air conditioning system and can change the system refrigerant charge level, blower speed, coil temperature, fan speed and other operating parameters to automatically and continuously maximize energy efficiency and minimize energy costs. The “portable” version is intended to be carried by service technicians and energy engineers, who use it to tune refrigerant charge, fan speeds, and other parameters; to identify underperforming components such as a fouled condenser coil, to maximize energy efficiency and reduce energy costs, while also identify systems that are justified for replacement. Both versions can help energy managers determine if it would be more cost effective to replace a poor performing rooftop unit, for example, than to replace the coil or the compressor.

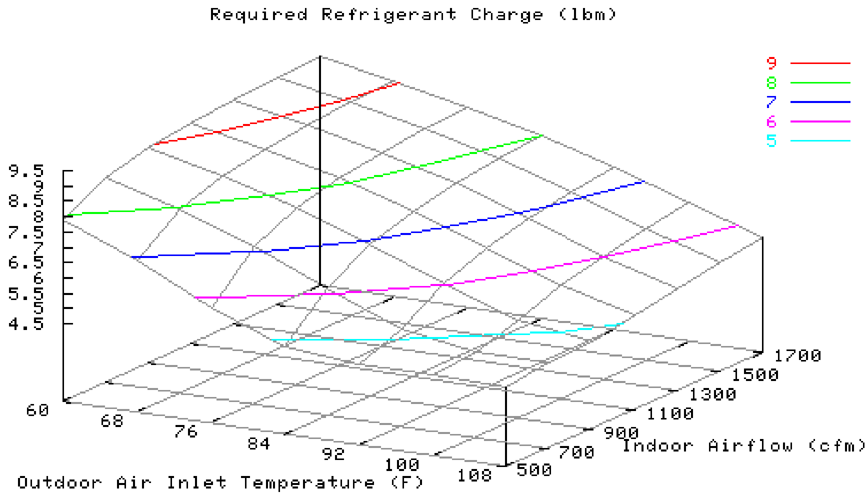


Figure 5. DX Modeling Results Showing How Optimum Charge Level Varies with Indoor Airflow and Outdoor Air Inlet Temperature.

2.3.1 Advantages of EER Optimizer Technology

Unitary DX air-conditioning systems are readily available in a range of capacities from 5 to 100 tons, have a relatively low first cost, and are easily serviced. However, even new best-in-class EER-14 commercial unitary[9] equipment does not give the 30% increase in efficiency over ASHRAE Standard 90.1 desired to meet federal energy reduction goals. Current energy efficiency minimums for new unitary air conditioning and heat pump systems[10] establish EERs of 9.8 to 11.2, depending on system capacity. However, the substantial base of installed unitary systems has an EER of 9.0 or less, dependent on equipment condition and maintenance history.[11]

Since unitary DX cooling units are often kept in operation long past their economic life, accurate measurement of EER enables facility managers to present a truer economic justification for major service or replacement of equipment that might otherwise be operated at dismal efficiency levels. The actual energy efficiency of a unit that's been in operation for several years could be reduced 10% - 40% from its like-new condition, although it might appear to be 'running fine' to occupants and service technicians. The reality is that many DX cooling units in service at DoD facilities are at times operating at suboptimal efficiency. EER Optimizer technology can maximize sustainable efficiency in both new and existing DX air conditioning systems for base facilities and mobile unit applications.

[9] Commercial unitary equipment is understood to mean equipment over 5 tons capacity utilizing 3-phase electric power. EER-14 means an Energy Efficiency Rating of 14 Btu/hr of cooling per Watt of electric usage.

[10] https://www.ecfr.gov/cgi-bin/text-idx?SID=8a5b57743b0296e02d26b410d48df7d0&mc=true&node=se10.3.431_197&rgn=div8

[11] *Efficiency Maine* suggests assuming EER of 9.0 for systems 5-10 years old and 8.0 for systems 10-15 years old - http://www.efficiencymaine.com/pdfs/EM_SAW_Rooftop.pdf

Competing technologies have not adequately addressed EER degradation. Service technicians typically deal with minor refrigerant leaks by simply "topping off" with refrigerant during seasonal service visits. It is difficult and time-consuming for technicians to locate a small leak, which is usually not repairable without the labor -intensive procedure of recovering, evacuating, and recharging a system. Systems are on occasion intentionally overcharged to compensate for pinhole leaks. Moreover, repeated topping off over time can result in drift of the mixture proportion in blended refrigerants, for example, more R-125 than R-32 could escape from a leaking R-410A condenser coil, since R-125 condenses first. Outside air temperature and airflow also affects optimal refrigerant charge level.

Maximizing the EER of DoD HVAC systems with EER Optimizer technology can provide a significant reduction in unitary system electric usage, providing DoD facility managers with a powerful tool for achieving energy efficiency goals. Implementation of the technology is straightforward and cost is low enough to meet payback period and return on investment thresholds for ESPC and UESC projects. EER Optimizer technology can support DoD performance contracting efforts to recover lost energy efficiency by identifying service actions needed to restore performance and to identify units ready for replacement by comparing actual operating EER with the factory EER ratings of the operating equipment versus high-efficiency replacement models. The economic impact to DoD of adopting EER Optimizer will depend on the frequency at which DX air conditioners are monitored and operationally optimized, the number of units targeted, and the baseline condition of the air conditioners.

Identification and implementation of service actions targeting cooling and energy performance can lengthen the economic life of DX package units. In addition to sustaining performance levels, EER Optimizer technology results in cooler compressor operation, reduced compression ratio, and protection from liquid entering the compressor, which tends to reduce the likelihood of compressor failure. Optimized refrigerant charge level and a clean condenser coil can, over many years of operation, curtail the commonly experienced rapid performance deterioration of DX package units and potentially add years of service life before replacement is needed.

Field demonstration under a full range of operating conditions at three sites across a wide range of climates showed that EER Optimizer can bestow a 10% to 30% improvement in system energy efficiency, depending on baseline equipment condition and load and climate factors. Energy savings can reach 40% when needed curative service actions are identified and carried out on units that otherwise appear to be performing satisfactorily.

2.3.2 Limitations of EER Optimizer Technology

Site-specific variables such as utility rates at DoD sites, and operating condition of existing HVAC equipment can strongly affect life cycle cost benefits relative to DoD economic criteria. A major consideration in evaluating EER Optimizer performance is the savings differential when applied to new or relatively new equipment versus equipment that has been in operation for several years, and the relative operating condition. For example, the demonstration at MCAS Beaufort involved a 2003 rooftop unit that uses obsolete R-22 refrigerant and has 9 years of operation, which resulted in unforeseen obstacles and a reduced savings opportunity due to its poor condition. The remaining life of older units represents a shorter time horizon for favorable payback economics.

Another consideration is how the size of the equipment affects the life cycle cost, payback period, and return on investment. Application cost of the onboard technology is only a weak function of unit size, for example the cost for installation on a large 40-ton air conditioner is not much more than cost for a smaller 10-ton unit. Since energy savings is proportionally greater on larger units, it follows that EER Optimizer is easier to justify economically on large units than small units.

Release of refrigerant during modification of the refrigerant circuit is a possibility that can be addressed through diligent onsite refrigerant management, including careful evacuation, leak checking, and collection & reuse of refrigerant when the system is opened for service. For example, a Leadership in Energy and Environmental Design for Existing Buildings (LEED-EB) best practice is to limit refrigerant release to less than 3% of total charge per year, and less than 25% over the remaining service life of the HVAC equipment. Refrigerant recovery and recycling has a well-known protocol with HVAC service providers, and this element can be stressed during the EER Optimizer retrofits.

A last consideration is factory warranty on the compressors of a new unit, which is typically 1-year from the date of installation for commercial unitary equipment (longer if an optional extended warranty is purchased). Systems older than one year are usually past the warranty period, and units that have had a compressor replacement in the past are not good candidates for retrofit. Installation of the on-board EER Optimizer system requires adding components to the refrigeration circuit, which could result in a factory compressor warranty claim being denied. Typically, the EER Optimizer installer assumes responsibility for compressor a warranty claim if the manufacturer will not. Note that compressor operating temperature will be reduced, and the compressor will be protected by the liquid-vapor separator installed upstream of the compressor, tending to lessen compressor stress.

3.0 PERFORMANCE OBJECTIVES

The EER Optimizer demonstration had the following major objectives, as detailed in Table 1:

- Verify significant improvement in operating IEER using the portable version, including 5% improvement for well-maintained, properly charged DX equipment, and 20% improvement in equipment in need of curative maintenance actions, such as coil cleaning and/or refrigerant leak detection & repair.
- Establish the cost effectiveness of the technology in both onboard & portable versions.
- Document reliable operation of onboard EER Optimizer technology.
- Document practicality, usefulness, and simplicity of diagnostics for portable EER Optimizer technology.

A. *Increase A/C units energy efficiency* – Metrics used to measure success are field-measured IEER (Integrated Energy Efficiency Ratio = Btu/hr cooling / total unit Watts) for each demonstration unit, and cooling season electric kWh consumed – both actual and estimated / adjusted to cooling degree-day (CDD) and heating degree-day (HDD) weather data for straightforward adaptation to other climate locations. The expectation is that each demonstration unit will exhibit measurable increase in IEER and commensurate decrease in energy use for a cooling season, relative to baseline IEER data collected for the demonstration DX units. Expect to average greater than 15% improvement in measured IEER for both handheld and onboard EER Optimizer demonstrations, at all demonstration sites.

All three onboard units exhibited a significant increase in IEER and commensurate decrease in normalized energy use for a cooling season, relative to baseline IEER measurements. The average improvement in measured IEER was 19.7%. The success criterion was met.

Targeted servicing indicated by the portable EER Optimizer unit fault detection & diagnostics, which were deemed cost effective, including coil cleaning, repairs, and correcting refrigerant charge provided IEER increase averaging 22% including the refrigerant charge corrections. The success criterion was met.

B. *Maintain or improve facility Indoor Air Quality (IAQ)* – Unitary HVAC systems currently on the market have fixed cooling coil surfaces. When energy efficiency measures are added, such as multiple or multi-stage compressors, or variable fresh airflow and supply air volume, dehumidification capability and fresh air delivery fluctuates. Typically, there is no control function that compensates to meet latent loads during periods of part-load sensible cooling. Thus, fresh air quantity is limited to about 20% of the unit airflow, with the remaining 80% being re-circulated air. To address the objective of improved IAQ in the conditioned space, we collected relative humidity (RH) and carbon dioxide (CO_2) data in the zones served by the demonstration DX units to establish a performance baseline. We continued to collect this data during EER Optimizer use, providing a basis for comparison between "before" and "after". Expect maintaining or improving CO_2 and RH levels in return air.

Table 1. Performance Objectives for EER Optimizer Demonstration.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives for HANDHELD Technology				
A. Increase A/C units energy efficiency	Energy used by A/C units vs cooling provided	Measured IEER and kW relative to baseline Btuh capacity	Average >15% improvement in energy efficiency	IEER Improvement 22%
B. Maintain or improve facility Indoor Air Quality (IAQ)	Ventilation effectiveness and indoor relative humidity (RH)	CO2 ppm level and %RH of unit return airflow from space relative to baseline	Same or improved ventilation level and relative humidity	Same or improved ventilation and relative humidity
C. Demonstrate cost effectiveness of Handheld unit technology	Cost of utilizing technology relative to energy savings	Handheld unit & labor costs vs estimated annual energy cost reduction	Overall payback period of 6 years or less and Return on Investment of >20%	0.4 to 1.1 years payback period and 1.6x investment
D. Maintain or improve reliability of the A/C unit	Unplanned and emergency repairs needed to maintain subjective comfort	Number and cost of needed repair actions	Same or reduced level of unplanned and emergency repair severity	Reduced number and cost of unplanned and emergency repairs
Quantitative Performance Objectives for ONBOARD Technology				
A. Increase A/C units energy efficiency	Energy used by A/C systems vs. cooling provided	Measured IEER & kWh relative to baseline Btuh capacity	Average >15% improvement in energy efficiency	IEER Improvement 19.7%
B. Maintain or improve facility Indoor Air Quality (IAQ) and Comfort	Fraction of time that IAQ meets ASHRAE 62.1 and 55 recommendations	CO2 ppm level , temperature F, and %RH of conditioned space	Same or increase in % of hours IAQ and Comfort is satisfactory	Same or improved IAQ and Comfort levels
C. Demonstrate cost effectiveness of Onboard controller technology	Cost of installed technology relative to energy savings	Installed equipment cost vs measured energy cost reduction	Payback period of 6 years or less and Return on Investment of >20%	4.8 years payback 22% ROI
D. Maintain or improve reliability of the A/C system	Unplanned and emergency repairs needed to maintain subjective comfort	Number and cost of needed repair actions	Same or reduced level of unplanned and emergency repair severity	Reduced number and cost of unplanned and emergency repairs
Qualitative Performance Objectives				
E. Manageability using existing facility HVAC staff & resources	Field assessment by HVAC technicians usually working on demonstration units	Identify critical performance and training needs	Concurrence of HVAC staff supervisors at demonstration sites	HVAC technicians agreed technology can be maintained with existing staff.
F. Reliability of A/C unit relative to reliability of baseline unit	Field assessment by HVAC staff at demonstration sites	Logged technician hours and refrigerant lbs-oz added vs baseline	Concurrence that unit performs as well or better than baseline unit	Unit was as or more reliable during test peoriod than baseline
G. User satisfaction	Likert-type Scale	Survey data	No measureable decrease in satisfaction relative to baseline level	Responses more positive for the test period than baseline

Overall, indoor air quality and thermal comfort was improved or unchanged at all three demonstration sites. At CCAFS, Temperature was 1.1 degrees-F cooler and relative humidity was slightly improved on average. At MCASB there was no significant change in humidity or ventilation for the test period relative to the baseline data. Space temperature was about 2 degrees-F warmer due to a set point change by the facility manager in accordance with energy policy. At Fort Irwin, temperature control was improved in the test period relative to the baseline period, with the percentage of hours classified as "warm" dropping from 65% to 10%. There was no significant change in humidity or ventilation at the Fort Irwin demonstration. The success criterion was met.

C. *Demonstrate cost effectiveness of EER Optimizer technology* – Depending on scheduled use of handheld technology by HVAC staff at demonstration sites, assess life cycle costs of EER Optimizer relative to energy and O&M costs during demonstration period. For onboard demonstrations, compare life cycle energy and O&M savings to installed cost and expected life of EER Optimizer equipped unit. Expect demonstrations will show greater than 20% return on investment (5 year payback period) for both handheld and onboard EER Optimizer, using Building Life Cycle Cost (BLCC) analyses.

Payback period averaged 4.8 years and annual return on investment averaged 22% for the three onboard demonstration units. The success criterion was met.

Economics of the portable technology and subsequent servicing produced payback periods ranging from 0.4 to 1.1 years overall, with savings-to-investment ratio (SIR) ranging from 1.0 to 2.4 for the groups of 10 packaged HVAC units at the three DoD installations. Annual return on investment averaged 1.6 times implementation cost. The success criterion was met.

D. *Maintain or improve reliability of the A/C unit* – We compared repair and downtime of demonstration units during demonstration periods with baseline data for all demonstration sites. Expectation is the same or reduced level of unplanned and/or emergency repair, compared to baseline, for demonstration units.

There was a reduction in the level and severity of unplanned and/or emergency repairs, from baseline season to test season at all three onboard demonstration sites. The types of service actions needed in the test period had a lower cost associated with them, indicating that the 57% average reduction in total service costs is at least partially attributable to the EER Optimizer technology. The success criterion was met.

E. *Manageability using existing facility HVAC staff & resources* – The measure of success for this objective was the judgment of maintenance supervisors at the demonstration sites that the demonstration units can be serviced and maintained with existing staff, and the absence of a need for critical maintenance interventions. Advantek engineers assisted and trained staff at the demonstration sites on principles and use of EER Optimizer, and were on-call for consultation if questions arose during O&M of demonstration units. Demonstration units with onboard EER Optimizer were fully instrumented for Advantek to monitor real-time operation and conditioned space parameters and quickly identify O&M anomalies. We set up a quick response system with local HVAC staff for dealing with needed maintenance and repair of demonstration units.

We surveyed acceptability of both handheld and onboard EER Optimizer versions with HVAC staff and management at all demonstration sites. We documented user acceptance and perception of value for EER Optimizer relative to baseline O&M operations.

HVAC technicians at all three demonstration sites agreed the technology can be serviced and maintained with existing staff. Some technicians stated and most others agreed that the remote fault detection & diagnostics feature of the EER Optimizer system is a key benefit for them. The success criterion was met.

F. Reliability of A/C unit relative to reliability of baseline unit – Reliability of commercial unitary HVAC equipment is a function of initial system design (unit sizing, ductwork, controls, etc.), operating environment, maintenance practices, and user control, as well as manufacturer-determined robustness of technology. To evaluate reliability, we assessed reliability of the base demonstration HVAC equipment using operating and maintenance data collected prior to using EER Optimizer for adjusting the equipment. Data was collected on the demonstration units' operation and energy use during the period EER Optimizer was being used, as well as interviews from installation staff responsible for O&M of the demonstration units. This data was used to compare relative reliability of the base units to the retrofitted units.

At all three demonstration sites, the onboard unit during the test period was as or more reliable than during the baseline and transition periods. The success criterion was met.

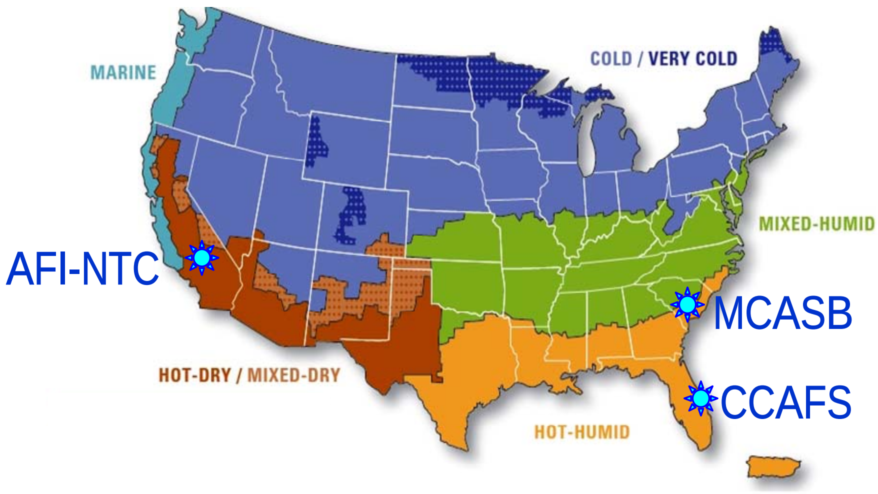
G. User satisfaction – Using a Likert-type survey instrument, occupants at the demonstration sites were surveyed on the performance of the demonstration equipment using EER Optimizer. The survey was designed to measure changes in satisfaction with the modified units.

Overall, the survey responses were more positive for the test period than they were for the baseline period. The largest improvement was at Fort Irwin (AFI), presumably because of the cooler and more consistent temperature and improved air circulation provided by the EER Optimizer technology. Most of the improvement at CCAFS indicated improved ventilation air flow. There was no significant improvement in the MCASB responses. The success criterion was met.

4.0 FACILITY / SITE DESCRIPTION

Demonstration sites for both handheld and onboard versions of EER Optimizer are:

1. Cape Canaveral AFS (CCAFS) / Naval Ordnance Test Unit (NOTU) is located within a mile of the seacoast in Cape Canaveral, Florida.
2. Marine Corps Air Station Beaufort (MCASB) is located in coastal South Carolina.
3. Army Fort Irwin National Training Center is located in the Mojave Desert near the Nevada - California border.



4.1 FACILITY/SITE LOCATION & OPERATIONS

4.1.1 Marine Corps Air Station Beaufort, SC Demonstration Site

Marine Corps Air Station Beaufort (MCASB) is a 6900-acre installation located 3 miles north of the city of Beaufort, South Carolina. The base hosts operations and support for seven squadrons of Marine F/A-18 Hornets and two Navy F/A-18 squadrons, with 700 Marine and Navy personnel, and 600 civilian personnel supporting the 3,400 personnel of Marine Air Group 31. The base was first commissioned in 1943 and in 2010 was selected for assignment of squadrons of the F-35B, Marine version of the Joint Strike Fighter aircraft, along with a large F-35B training facility.

The EER Optimizer demonstration site is Building 1283, the Base Exchange facility, which has 11 unitary air conditioning units located on the roof. One of these units, RTU-2, a 2003 20-ton Trane package unit utilizing R-22 refrigerant, was the demonstration platform for retrofit with Advantek's ClimaStat® technology in 2011 – 2013 [12]. Building 1283 is connected to a base-wide direct digital control (DDC) network, which monitors basic operational conditions in the building continuously, including the status of all roof-mounted unitary equipment.

[12] ESTCP project EW-201144 final report, *Demonstration and Testing of ClimaStat® for Improved DX Air-Conditioning Efficiency*, April 2013, Advantek Consulting, Inc.

The building also is connected to an advanced energy metering system, and RTU-2 is individually instrumented for operating status. MCASB Public Works monitors base energy usage and regularly reports usage relative to an FY 2003 baseline of 94,870 Btu/ft^2, with usage of 78,380 Btu/ft^2 at 4th Quarter FY 2013 and 65,880 Btu/ft^2 at 4th Quarter FY 2016.

Figure 6. Location of Marine Corps Air Station Beaufort, SC 50 Miles Southwest of Charleston, SC.

Figure 7. Building 1283 Base Exchange at MCAS Beaufort.

4.1.2 Cape Canaveral Air Force Station, FL Demonstration Site

Cape Canaveral Air Force Station, Florida (CCAFS) is an installation of the Air Force Space Command's 45th Space Wing, headquartered at nearby Patrick Air Force Base (PAFB). CCAFS is the primary launch head of America's Eastern Range. The CCAFS Skid Strip provides a 10,000-foot runway close to the launch complexes for military airlift aircraft delivering heavy and outsized payloads to the Cape. The facility is southeast of National Aeronautics and Space Administration's (NASA's) Kennedy Space Center on adjacent Merritt Island. There are a number of mission partners, including:

- National Aeronautics and Space Administration (NASA)
- Naval Ordinance Test Unit (NOTU)
- 920th Rescue Wing (920 RQW)
- Defense Equality Opportunity Management Institute (DEOMI)
- Air Force Technical Applications Center (AFTAC)

Naval Ordnance Test Unit (NOTU) provides technical support for flight test and analysis for ballistic missiles. NOTU is an Echelon III Department of the Navy field command under the cognizance of the Director, Strategic Systems Programs. NOTU operates the Navy Port at Port Canaveral, supporting more than 200 visits a year by submarines and surface ships of the U.S. Atlantic Fleet and foreign navies. NOTU facilities include a missile assembly and checkout facility, ordnance storage magazines, a launch pad, data acquisition and test instrumentation facilities, support shops and offices and the Poseidon and Trident wharves.

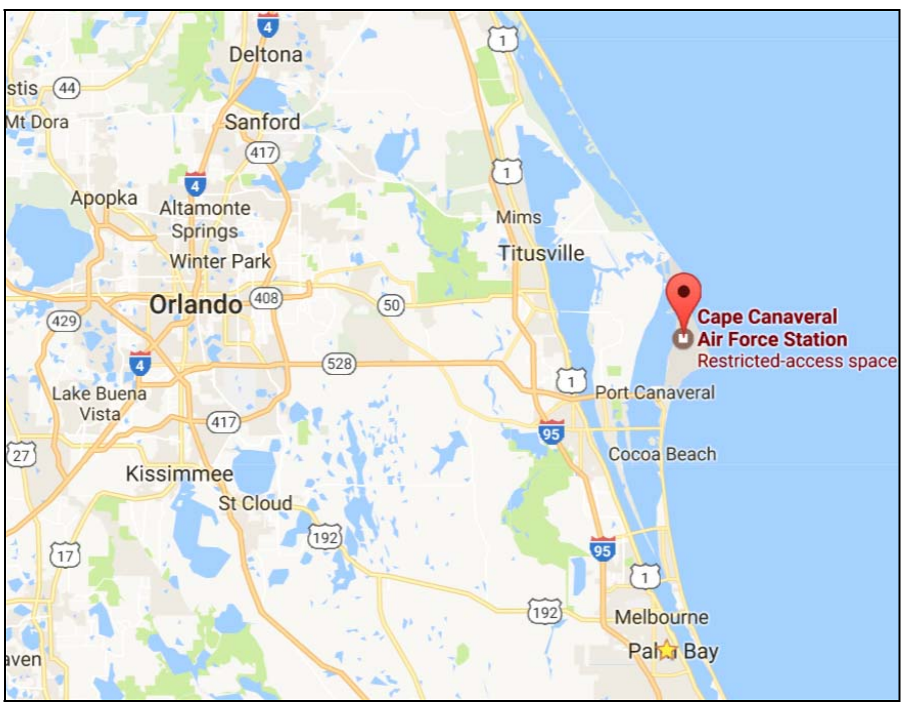


Figure 8. Location of NOTU / CCAFS 50 Miles East of Orlando, FL

The 45th Civil Engineering Squadron (CES) is the largest squadron within the 45th Space Wing, overseeing 14 operating locations with 13,100 personnel -- including three airfields, seven launch complexes, and 1,500 homes. Much like a public works department for a civilian city, the civil engineers assigned to the 45th CES maintain all utilities and facilities at Patrick AFB, Cape Canaveral AFS, Jonathan Dickinson Military Tracking Annex, Malabar Annex, Ramey Solar Observatory, Puerto Rico, Antigua Air Station, West Indies, and Ascension Island. The 45th CES is charged with supporting the Air Force strategic goal of an energy intensity reduction of three percent per year for 10 continuous years. Each day, Patrick Air Force Base and Cape Canaveral Air Force Station combine to spend approximately $40,000 on utilities (electricity, gas and water). The 45th Space Wing spent $30 million on facility energy use last fiscal year.

NOTU Building 1115 at CCAFS was a demonstration site for the ESTCP project demonstrating ClimaStat® in a new Carrier 7½ -ton packaged air-conditioning package unit installed in 2012.

Figure 9. CCAFS Hangar Y, NOTU Engineering Development Lab, FL.

4.1.3 Fort Irwin, CA Demonstration Site

Fort Irwin is a seven square mile Army National Training Center (NTC) located in the Mojave Desert, in Southern California about half way (160 miles) between Los Angeles, California and Las Vegas, Nevada. It sits at an elevation of 2500 feet and has a daytime population of 25,000. The installation is part of the Army Installation Management Command (IMCOM) where the 11th Armored Calvary Regiment, the Blackhorse Calvary, is stationed to provide an enemy force to units on training rotation. Fort Irwin's energy budget is over $30 million per year with a 34 MW peak electrical demand and it pursues a net zero energy strategy.

The EER Optimizer demonstration site is building 606, Public Works / Environmental. A 2010 12½-ton dual-compressor Carrier R410a package heat pump was retrofitted with the on-board version. The building and its air-conditioning system is typical of many at Fort Irwin.

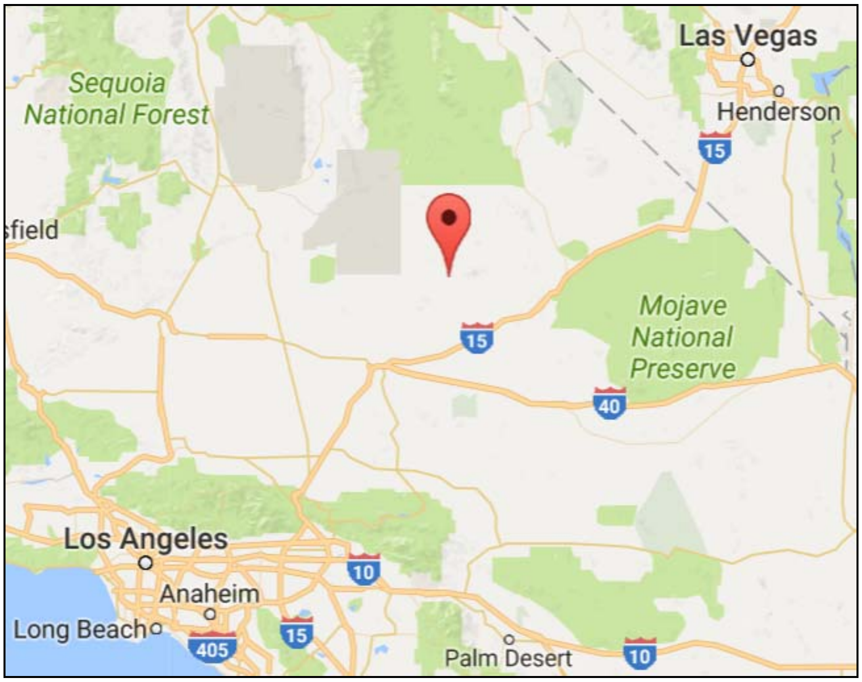


Figure 10. **Location of National Training Center, Fort Irwin, CA 160 Miles between Los Angeles, CA and Las Vegas, NV.**

Figure 11. **DPW Environmental Building 606 at Fort Irwin, CA.**

4.2 FACILITY / SITE CONDITIONS

Three demonstration sites provided a full range of test conditions for the EER Optimizer technology to demonstrate the flexibility and efficacy needed for the widely varying climates of DoD installations.

The Florida and South Carolina sites are located at humid and temperate ends of the ASHRAE

hot & humid climate region and both installations have several buildings served by candidate unitary-DX equipment with considerable cooling load. The Florida site is in ASHRAE Climate Zone 2A with a winter heating season limited to a few days of below normal temperatures when heating is needed and cooling / dehumidification is needed almost year round. CCAFS experiences 3290 cooling degree-days per year on average. The South Carolina site is in ASHRAE Climate Zone 3A with a 4-month heating season, during which no cooling is needed and heat is provided by a gas burner. MCASB experiences 2650 cooling degree-days per year on average.

Fort Irwin, California has the high ambient temperatures and low humidity of the hot & arid Mojave Desert, needing much different optimal refrigerant levels than the Florida and South Carolina sites, especially due to the low critical temperature of R-410A as compared with legacy R-22 equipment. The California site is in ASHRAE Climate Zone 3B and experiences 2600 cooling degree-days per year on average. The DX units at Fort Irwin are heat pumps, which provide winter heat during the 4-month heating season, which can be severe at times.

5.0 TEST DESIGN

<u>Fundamental Problem</u>: *Unitary cooling and heat pump equipment rarely operates at peak EER. Operating conditions vary daily and seasonally with weather, and occupant loading and set points. And, equipment condition declines over years as components wear, foul and degrade, and due to minute refrigerant leaks.*

<u>Demonstration Question</u>: *Can EER Optimizer technology be utilized to cost-effectively maximize the operating efficiency of air conditioners and heat pumps under the full range of climate and maintenance conditions experienced at DoD sites?*

<u>Hypothesis</u>: *EER Optimizer technology will cost-effectively increase the operating efficiency of the demonstration air conditioners by an average of at least 15%.*

5.1 CONCEPTUAL TEST DESIGN

The testing aims to validate the assertions that EER Optimizer technology increases the operating energy efficiency level of DX package systems and reduces annual energy consumption and costs; results in no degradation of indoor air quality; operates reliably without adverse maintenance effects; and is cost effective. Three demonstration air conditioners field-equipped with the onboard EER Optimizer system were fully instrumented on both the airflow process and refrigerant cycle with dedicated data loggers and 45 sensors. The portable EER Optimizer technology was evaluated using measurements of the energy efficiency performance of ten air conditioner units at each demonstration site made to establish baseline and serviced performance levels.

Metrics used to measure success were field-measured EER (Energy Efficiency Ratio = Btu/hr cooling / total unit Watts][13] and IEER (Integrated Energy Efficiency Ratio)[14]; cooling season electric kWh consumed – both calculated and normalized to cooling degree-day and heating degree-day (CDD and HDD) weather data for adaptation to other climate locations; actual tracked materials and labor costs versus realized electric savings; IAQ via space relative humidity, temperature, and carbon dioxide levels and the fraction of occupied hours which these levels are deemed acceptable; and maintenance costs and the number and severity of unplanned or emergency maintenance interventions, if any.

Demonstration comparisons were conducted by way of two methodologies: (1) on same units using 'with / before' versus 'without / after' for the onboard version and (2) on several DX units using 'before' versus 'after' for the portable version. For the onboard version, web-based 45-channel data loggers were used to collect and store data at 1-minute intervals continuously throughout the project period. Data verification was performed every week by plotting the reduced data, allowing the analyst to visually locate significant outlying points that could indicate erroneous data collection, sensor issues, or operational problems and initiate corrective action.

[13] ANSI/ASHRAE Standard 37-2009. Methods of Testing for Rating Electrically Driven Unitary Air-Conditioning and Heat Pump Equipment. Approved by ANSI on 25 June 2009.

[14] ANSI/AHRI Standard 340/360-2007 with Addenda 1 and 2 (Formerly ARI Standard 340/360-2007), 2007 Standard for Performance Rating of Commercial and Industrial Unitary Air-Conditioning and Heat Pump Equipment. Approved by ANSI on 27 October 2011.

For the handheld version, the portable EER Optimizer instrument along with supplementary portable meters served to gather energy efficiency metrics before implementing indicated adjustments and service actions, and again afterwards. The following data was collected via calibrated and verified sensors to enable calculation and analysis of accurate performance metrics and the effect of the technology on system operation:

- Independent variables are the binary change of status 'with' versus 'without' the subject technology, EER Optimizer; along with the background independent variables of ambient temperature (F), humidity (%RH), carbon dioxide level (ppm), occupancy status, and time of day / day of week.
- Dependent system-level variables to be measured are: System power demand (kW) and energy consumption (kWh); system cooling delivered in terms of both sensible and latent (Btuh); and occupied space air temperature (F), relative humidity (%RH), and carbon dioxide level (ppm) differential with respect to ambient carbon dioxide level [15].
- Dependent component-level variables to be measured are: compressor amps, fan electric power (Watts), refrigerant pressures and temperatures at the inlet and outlet of the compressor (psig and F); refrigerant flow rate (gpm); refrigerant charge (lbm); coil air face velocity (fpm), inter-component air and refrigerant temperatures (F); and control signals status and voltages [16].

The on-board demonstration units were instrumented on both the airflow process and refrigerant cycle. Airflow process measurements included unit and cooling coil entering / leaving temperature; humidity, and dew points; and air volume flow rates. Refrigerant cycle measurements included temperatures at the inlet and outlet of each component (compressor, condenser coil, evaporator coil, TXV), high- and low-side and reservoir pressures, and refrigerant mass flow rate. Energy measurements included total unit power demand along with compressor amperage, fan amperage, and control voltages. Objective evaluations of indoor air quality were via occupied space temperature, relative humidity, and carbon dioxide (CO_2) level. Comfort evaluation was via the Predicted Mean Vote (PMV) method; the PMV index predicts the mean response of a larger group of people according the ASHRAE thermal sense scale.

The imbalanced refrigerant level of each of the DX units were measured before any service actions are taken (as found onsite) using the EER Optimizer hand held instrument. A tracking procedure consisting of a simple unit-mounted log book was used to quantify actual field technician time/labor before and after technology implementation to track refrigerant charge additions and assess the savings associated with maintenance issues was implemented.

Sensors and data logging equipment were installed on the selected and site-approved DX units under quality assurance procedures. Next, baseline performance characterization was established over the first cooling season (2014). Then, the onboard EER Optimizer technology were installed on three existing unitary systems (one at each site, 2015), while the energy efficiency of ten other units at each site was evaluated and maximized using the portable EER Optimizer technology (2015-16), and baseline comfort data was collected. Operational testing proceeded from the

[15] Boyer, Eric., "Rooftop HVAC Systems Monitoring." Onset Computer Corporation 2009.
[16] 2007 Standard for Performance Rating of Commercial and Industrial Unitary Air-Conditioning and Heat Pump Equipment." ANSI/AHRI STANDARD 340/360-2007

middle of the second cooling season (2015), through the heating season (2015-16) and to the end of the third cooling season (2016), with refined technology and service procedure implemented on identified units in parallel with technology transfer activities at the demonstration sites.

5.2 BASELINE CHARACTERIZATION

Baseline data were collected before installing the EER Optimizer onboard system on the three demonstration DX units, and before any adjustments or maintenance are carried out on the 30 DX units using the portable instrument. Additional onboard baseline data was collected during the third cooling season during selected benchmark days when the EER Optimizer control functions were disabled to operate the unit in its baseline configuration to obtain a performance benchmark. Baseline information is provided together with test results in section 5.6 below to facilitate direct comparison of test values with baseline and benchmark values.

Logger systems were used for collection of 45 points of operational data from each of the three DX air conditioners selected for the onboard version of the EER Optimizer technology. Operational data were collected from the start of the baseline phase through the date that the DX air conditioners were retrofitted with the EER Optimizer system during the second summer, and continued through the remaining weeks of the second summer, winter, to the end of the third summer demonstration phase and through the winter. The baseline data collection period was the first summer cooling season, approximately 16 weeks. Data collected is as described above in section 5.1 continuously for all for phases.

The baseline refrigerant charge was determined using the portable handheld instrument via the following procedure: First, the "as is" cooling, power and efficiency performance was measured as found with no refrigerant addition / removal. Then, the refrigerant level of each of the DX units were measured before any service actions were taken (as found onsite) by recovering and weighing the existing refrigerant in each unit. The mass of refrigerant, ranging from 3.8 to 26.6 lbs per circuit, was measured using a calibrated refrigerant scale with a resolution of 0.5 ounces (0.03 lbs). The measured refrigerant mass was compared with the air-conditioner's factory charge as specified on its nameplate to determine the amount of under or overcharge.

A log book was provided inside each unit, with entry spaces for date, work done, and refrigerant added. These data were combined with refrigerant costs and labor rates to arrive at a maintenance cost / savings value for each unit. Also, logging the loss of refrigerant to the atmosphere was considered a sustainability issue, providing a measure of avoiding greenhouse gas release from otherwise undetected leaks in the demonstration equipment.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

EER Optimizer technology provides an accurate and practical analysis of the energy efficiency of any operating DX air-conditioner or heat pump unit, expressed in standard units by measuring the cooling or heating capacity and the power usage. The EER Optimizer CPU runs software that computes the Integrated Energy Efficiency Ratio (IEER) according to AHRI 340/360 *Performance Rating of Commercial and Industrial Unitary Air-conditioning and Heat Pump Equipment*. The cloud linked optimizer system software is easily updated via code changes that are automatically pushed out to all onboard and portable units as a soft update.

The technology provides web monitoring & reporting of EER, IEER, Tons Capacity and detected faults such as low refrigerant, stuck TXV, restricted airflow, broken economizer, compressor wear, or fouled coil, viewable at EERoptimizer.com

The handheld version of the technology is embedded in a portable instrument, which is intended to be connected to various points on an operating air-conditioner or heat pump, and removed at the end of a typical 1- to 2-hour service call. The portable unit is web connected for remote technical assistance, storing readings on a cloud server for later retrieval and analysis, and to support evaluation of historical trends, reporting, and documentation. Diagnostics include low refrigerant, stuck TXV, restricted airflow, compressor wear, and fouled coil. The onboard version is embedded in a unitary controller, which is permanently installed into the DX unit. It controls fan and blower speeds, damper position, and refrigerant charge level, as well as performing fault detection and diagnostics via an internet-connected web interface. Sensitive diagnostics detect issues before they become problematic.

The onboard version of the technology makes adjustments for the purpose of maximizing measured energy efficiency in a relational feedback loop utilized to optimize cooling or heating capacity relative to power consumed. The target is maximum EER while precisely meeting sensible and latent loads. Optimum parameter adjustment is a function of the load under which the air conditioner or heat pump is running. Maximum EER is continuously achieved by adjusting each operating parameter to realize an increase in EER, as conditions such as cooling load, humidity, and ambient temperature are changing. The onboard control functions layer atop the existing OEM unitary control board, which continues to provide basic functionality such as compressor cycling in response to thermostat calls and high- and low- pressure safety protection. Failure of the onboard controller results in the DX unit reverting to the OEM board, as if the onboard controller were not installed.

The onboard technology has the capability of simultaneously optimizing numerous operating parameters, including the discharge air temperature setpoint, supply fan airflow, cooling coil temperature setpoint, bypass damper position, economizer position, condenser fan speed, liquid refrigerant subcooling setpoint, condenser split temperature setpoint, refrigerant charge level, compressor speed, expansion valve position (if the unit is equipped with an electronic expansion valve), and refrigerant composition (if the unit is equipped with a component separator). Accordingly, the three demonstration units were equipped with commercially available variable speed supply and condenser fans, a bypass damper with a commercially available actuator, and a refrigerant charge reservoir and commercially available solenoid valves; if the units are not already equipped, in order to demonstrate simultaneous optimization of several parameters.

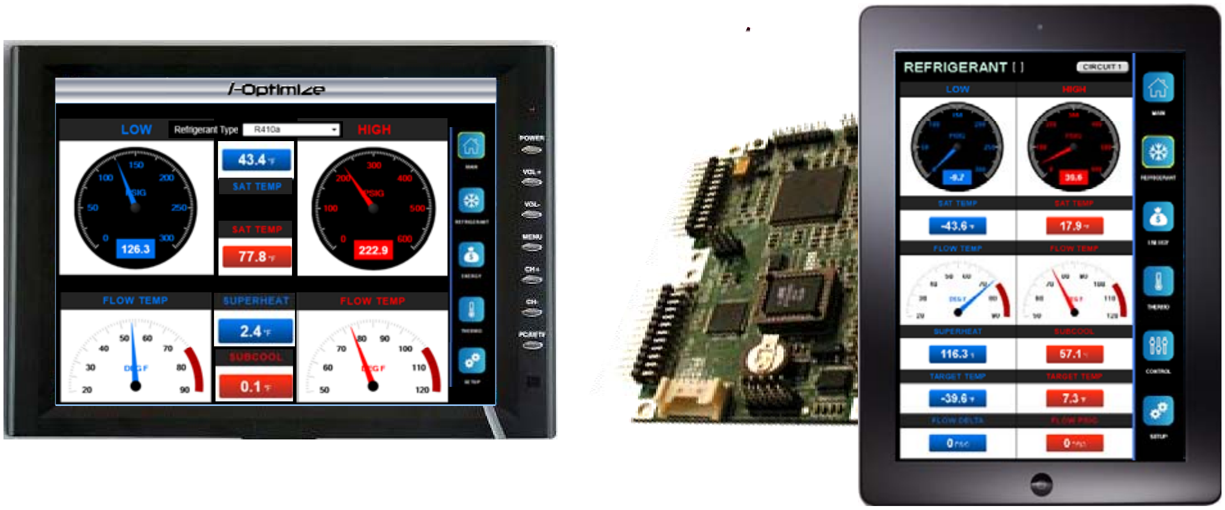


Figure 12. Two embodiments of the Demonstrated Technology ¶ (Left) handheld instrument for portable measurement & diagnosis, and (Right) onboard controller to optimize & report operational parameters, shown on the screen are refrigerant low and high pressures, temperatures, superheat and subcool.

Figure 13. Onboard Unit Manual Control Screen Showing Knobs for Fan Speed, Damper Position, Blower Speed, and Refrigerant Charge / Discharge Valve Position.

When the user selects MANUAL operating mode, the automatic and optimization functions are suspended and the manual controls respond to local user input.

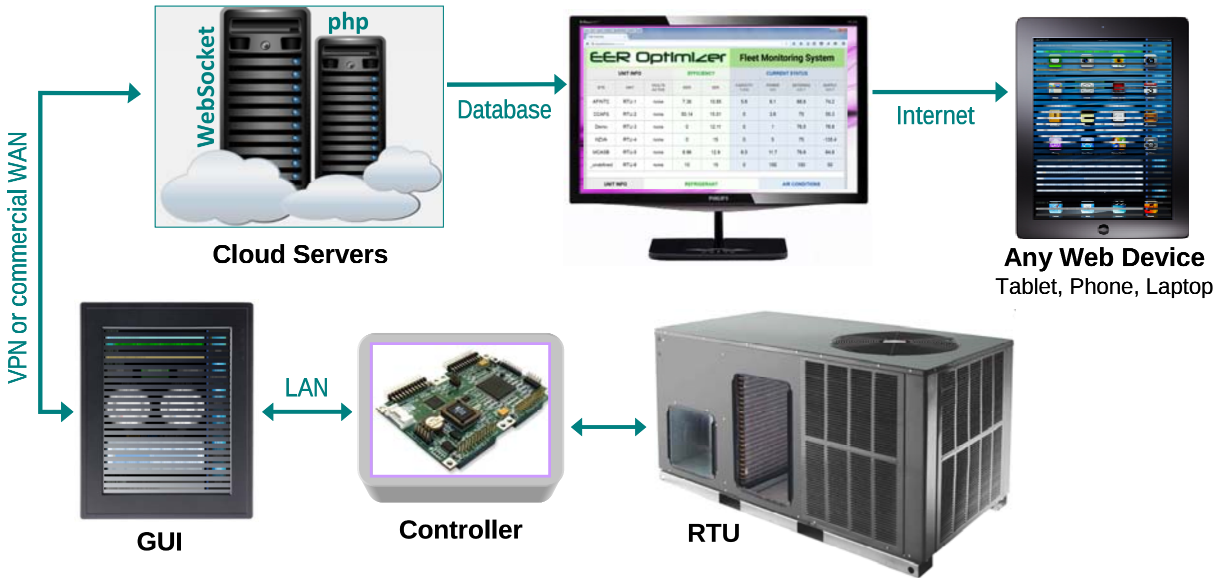
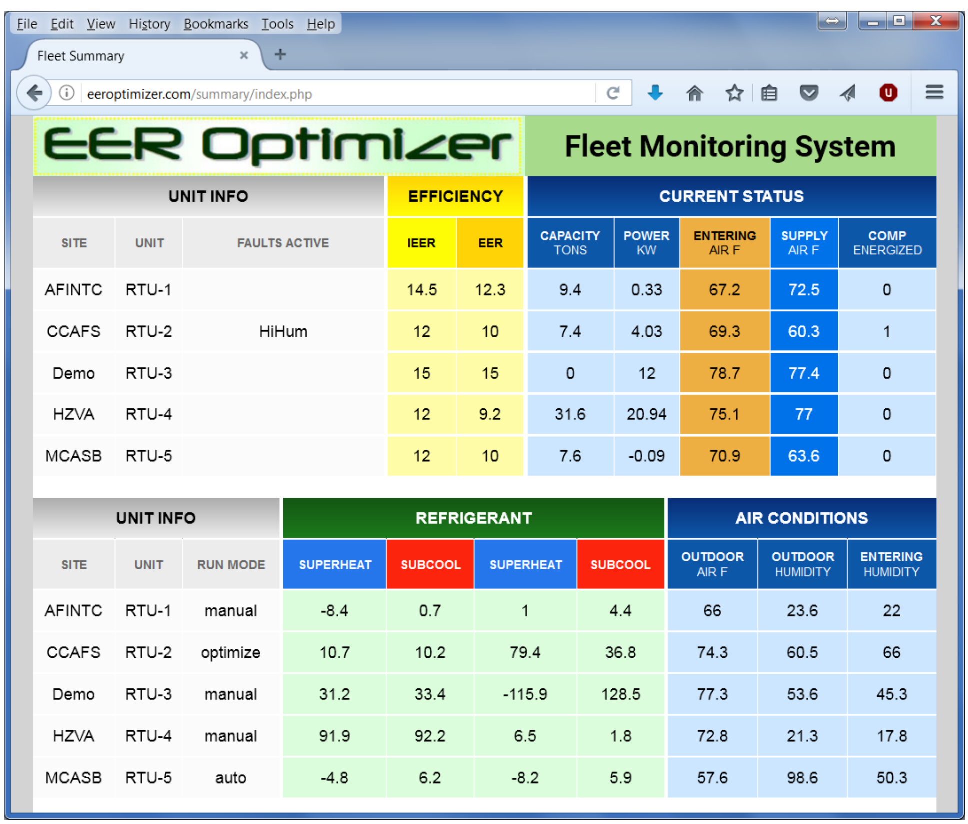


Figure 14. Connection Diagram Showing Data Path between the Air Conditioner and Any Web Connected Device Such as a Tablet, Phone, Laptop, or Desktop Computer.

The touch screen graphical user interface (GUI) serves as the air conditioner's control panel. Cybersecurity is addressed via an isolated VPN.



UNIT INFO			EFFICIENCY		CURRENT STATUS				
SITE	UNIT	FAULTS ACTIVE	IEER	EER	CAPACITY TONS	POWER KW	ENTERING AIR F	SUPPLY AIR F	COMP ENERGIZED
AFINTC	RTU-1		14.5	12.3	9.4	0.33	67.2	72.5	0
CCAFS	RTU-2	HiHum	12	10	7.4	4.03	69.3	60.3	1
Demo	RTU-3		15	15	0	12	78.7	77.4	0
HZVA	RTU-4		12	9.2	31.6	20.94	75.1	77	0
MCASB	RTU-5		12	10	7.6	-0.09	70.9	63.6	0

UNIT INFO			REFRIGERANT				AIR CONDITIONS		
SITE	UNIT	RUN MODE	SUPERHEAT	SUBCOOL	SUPERHEAT	SUBCOOL	OUTDOOR AIR F	OUTDOOR HUMIDITY	ENTERING HUMIDITY
AFINTC	RTU-1	manual	-8.4	0.7	1	4.4	66	23.6	22
CCAFS	RTU-2	optimize	10.7	10.2	79.4	36.8	74.3	60.5	66
Demo	RTU-3	manual	31.2	33.4	-115.9	128.5	77.3	53.6	45.3
HZVA	RTU-4	manual	91.9	92.2	6.5	1.8	72.8	21.3	17.8
MCASB	RTU-5	auto	-4.8	6.2	-8.2	5.9	57.6	98.6	50.3

Figure 15. A Summary Screen Showing Status, Readings and Faults Detected from Several Air Conditioners Can Be Viewed from Any Web Browser or Mobile Device.

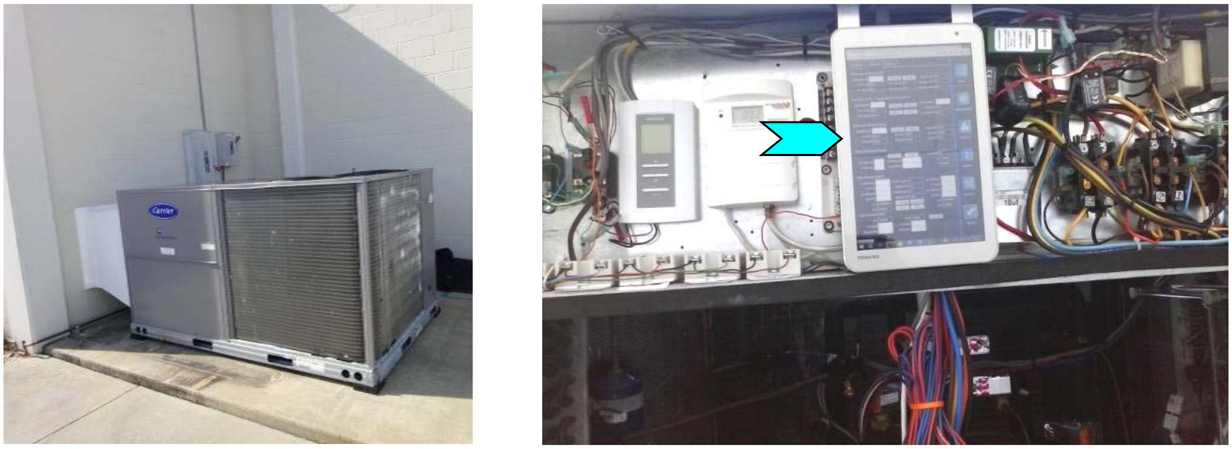


Figure 16. DX Air-conditioner Unit at CCAFS (left) with EER Optimizer Touch Screen GUI Installed in Control Compartment (right).

Figure 17. DX Air-conditioner Unit at MCASB (left) with EER Optimizer Touch Screen GUI Installed in Control Compartment (right).

Figure 18. DX Air-conditioner Unit at Fort Irwon (left) with EER Optimizer Touch Screen GUI Installed in Control Compartment (right).

The EER Optimizer CPU in demonstration systems is a Motorola based industrial grade single board computer (SBC), chosen for its ruggedness, reliability, and compliance with MIL–PRF–31032. The circuit boards are assembled in California, and undergo full-coverage functional testing in-house. This Motorola based SBC is used in other demanding applications, such as lab equipment, industrial chemical production, and locomotive traction control and is built with premium components. In contrast, low cost SBCs like Raspberry Pi focused on the hobby market are assembled outside the U.S. and undergo limited or no functional testing. Raspberry Pi is designed as a miniature Linux desktop. The non-deterministic nature of Linux prevents true real-time guarantees. The Motorola based SBC is designed only for industrial control purposes, and provides no attack vectors for malicious users or software on the network.

At the demonstration sites, cybersecurity was addressed via a virtual private network (VPN) on an isolated internet connection. In general, installations are accepting of Ethernet hardwire facility network connections over a virtual local area network (VLAN) or dedicated wide are network (WAN), WiFi has been used but is discouraged or not permitted. The nonstandard IT parts of the system are a webrelay and the SBC. Dependence on the network for execution of control strategies has been avoided, specifically, basic control functionality is available during a network outage; for example, blower, fan and compressor start/stop and basic speed control algorithms are internal to the SBC. For high level optimization, trending, remote monitoring and alarm functions, dependence on the network is unavoidable. A display panel and dedicated Level 2 front end are physically co-located with the equipment. If required, additional steps can be taken to protect critical functions from modification over the network, including barriers to manipulation, security diagnostic software, encryption, and two-factor authentication.

5.4 OPERATIONAL TESTING

The baseline phase was during the 2014 cooling season, when data was collected before installation of the technology, as listed in the table below. The test phase was the 2016 cooling season, when data was collected after the technology was installed and fully operational. The tables below list for each demonstration site the cooling degree-days for the respective year, the start and end dates of the data collection periods, the number of days and the cooling degree-days in the data collection periods. The baseline period at the Fort Irwin site (AFI) was delayed until repairs on the existing air conditioner unit were completed.

Table 2. Baseline and Test Data Period Start and End Dates and Cooling Degree-Days.

DATA PERIOD - Baseline

Site	CDD-2014	Start	End	Days	CDD
MCASB (SC)	2627	7/27/14	10/8/14	73	964
AFI-NTC (CA)	3225	9/2/14	10/4/14	32	529
CCAFS (FL)	3633	6/28/14	10/14/14	108	1804

DATA PERIOD - Test

Site	CDD-2016	Start	End	Days	CDD
MCASB (SC)	2851	6/8/16	9/7/16	91	1715
AFI-NTC (CA)	2788	6/8/16	9/26/16	110	2160
CCAFS (FL)	3588	6/5/16	9/8/16	95	1690

The 2014 baseline data was supplemented by periodic benchmarking during the 2016 cooling season by setting the technology run mode to "Manual," which suspends the automatic and optimization control functions. Benchmarking was performed to account for equipment wear and deterioration that occurred between the end of the 2014 baseline period and the start of the 2016 test period, a span of 20 months centered on the 2015 cooling season during which the technology was installed, calibrated, and refined.

Operating data was used to compare performance of systems with and without or before and after EER Optimizer technology implementation. The results were correlated to climatic (outside temperature, relative humidity) and operational variables (setpoint temperature, outside air ventilation, indoor relative humidity and carbon dioxide levels). The reduced and verified data were analyzed to calculate the effect on the performance objective variables; specifically, energy efficiency, energy cost, cooling and dehumidification performance and occupied space indoor air quality.

Energy efficiency parameters fully characterize system performance and are directly comparable with manufacturer's published data, as follows. Energy consumption was calculated from measured system power and run time. Sensible cooling performance was calculated using the temperature differential between the system inlet and outlet, and across the cooling coil. Dehumidification performance was calculated via the absolute humidity differential psychrometrically computed using temperature and relative humidity at the system inlet and outlet and across the cooling coils. Total cooling is then the sum of the cooling and dehumidification, and sensible heat ratio is the sensible cooling divided by the total cooling.

Total cooling was also calculated from the measured refrigerant pressure differential between compressor inlet and outlet, along with the temperatures at the same locations, and the refrigerant mass flow rate computed from the refrigerant volume flow rate and density using specialized software. Together with the system power, the energy efficiency ratio (EER) is calculated as the total cooling in units of Btuh divided by the system power in units of Watts. These results were statistically correlated with ambient air conditions to determine the effect of the operating environment on performance; for example, EER versus ambient temperature is useful for predicting energy usage at other locations. Other useful statistics calculated are average, maximum and minimum values, the standard deviation, and the percentile.

Space indoor air quality (IAQ) was evaluated by counting the number of data sample intervals during which the indoor space temperature, humidity, and carbon dioxide level are within the comfort parameters defined by ASHRAE Standard 62.1 *aka* "The IAQ Standard" and ASHRAE Standard 55 *aka* "The Comfort Standard." Typically, this means temperature between 72°F and 77°F, humidity between 50% and $60\%_{rh}$, and carbon dioxide level less than 700 ppm above outdoor ambient level, or less than 1000 ppm whichever is lower. The number of sample intervals multiplied by the interval length, divided by the total elapsed data collection period yields the fraction of time IAQ is deemed satisfactory by 80% of a statistical group of occupants. These parameters were compared 'with' versus 'without' the EER Optimizer onboard version.

Each demonstration unit was instrumented to collect the following data. All data were recorded at 1-minute intervals.

Refrigerant circuit – temperatures entering and exiting evaporator coil, pressure and temperature at suction and discharge of compressors, temperature entering and exiting condenser coil, temperature entering and exiting liquid heat exchanger separator, refrigerant flow rate, refrigerant receiver mass, and temperature of air exiting condenser coil.

Air stream – Relative humidity and temperature of outside air, return air entering evaporator coil and supply air exiting unit; differential pressure across supply-to-return; temperatures of air exiting evaporator coil at two locations and air bypassing evaporator coil; face velocity of air exiting evaporator coil.

Electrical energy – Power and electricity used by compressors, blower, and fans; total unit kW/kWh; compressor Amps; fan and blower Watts.

Refrigerant charge measurements were made after incrementally adjusting the refrigerant level by, for example, ±2.5% and ±5.0% of nominal or less/more as indicated to maximize performance. If a large amount of refrigerant was added to maximize performance, detection equipment was used to pinpoint leaks and mark them for repair as part of the identified needed service actions. Finally, refrigerant levels were fine-tuned for maximum EER at the actual operating condition. The imbalanced refrigerant levels of each unit were compared against the improvement in efficiency obtained by fine-tuning the level using the EER Optimizer instrument.

Nearing completion of the respective demonstration projects, each host facility point of contact were asked about their interest in keeping the EER Optimizer system in operation or, alternatively, returning the units to their pre-demonstration condition. All three hosts indicated a preference for keeping the EER Optimizer system in operation if possible. The EER Optimizer systems at CCAFS and Fort Irwin will be upgraded to the latest version. The system at MCASB will be left as-is because the air conditioner unit is at the end of its usable life and will be replaced.

5.5 SAMPLING PROTOCOL

Data was collected continuously from the start of the baseline period at the beginning of summer 2014, through the end of the test period at the close of summer 2016. There were 45 sensor channels at each site. The sensors were sampled at 60 second intervals by the data logging systems, and every sample was written every 1-minute to a comma delimited text file (.csv) that was uploaded to a cloud server daily and a backup server at a different physical location. The files were automatically backed up to a dedicated cloud account once each day, and in turn the backup folder was backed up on a server located at the Advantek office in Melbourne, FL, which in turn was backed up to a cloud server at weekly intervals. The sampling rate was at times temporarily increased to 10 seconds when more detail was required.

Data was made available in near-real-time (within 10 minutes) to all project personnel by secure connection via web browser interface. Files containing the most recent data were uploaded at approximately one week intervals into Excel files for further analysis by a project engineer, who would look for anomalies such as bad sensors or failed components, and initiate further investigation and/or corrective action as appropriate. Data verification was also performed approximately weekly by plotting the reduced data, allowing a project engineer to visually locate significant outlying points that may indicate erroneous data collection or operational problems.

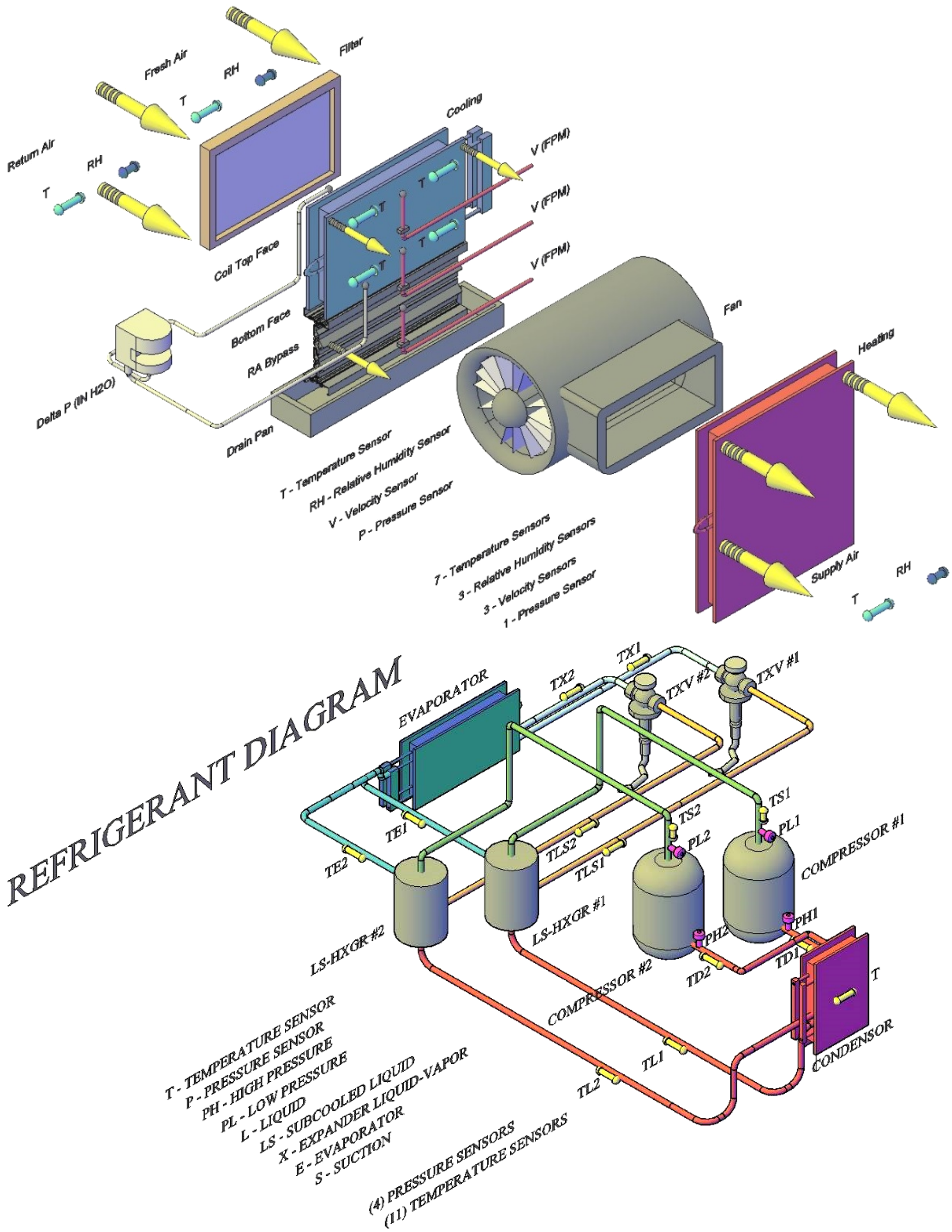


Figure 19. Air Circuit Diagram (top) and Refrigerant Circuit Diagram (bottom) Showing Location of Sensors.

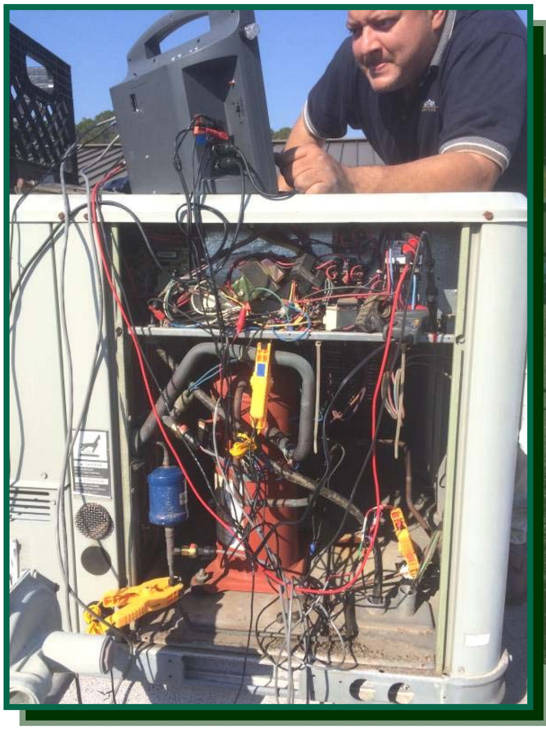


Figure 20. The Portable EER Optimizer Technology Being Used by a Technician at MCASB to Measure the Energy Efficiency and Detect & Diagnose Faults on a Small Rooftop Package Unit.

Figure 21. The Portable EER Optimizer Technology Being Used by a Technician at CCAFS to Measure the Energy Efficiency and Detect & Diagnose Faults on a Small Ground Mounted Package Unit.

User satisfaction survey questions were adopted from the survey instrument used by ASHRAE in evaluation new technology demonstrations: The Occupant Indoor Environmental Quality (IEQ) Survey™ from the Center for the Built Environment at Lawrence Berkely[17]. Questions applicable to this demonstration are listed below; the subject was asked to select a response from a range of 1 to 5 with 1 being most negative and 5 being most positive.

ANONYMOUS AIR CONDITIONING SURVEY

Scale for questions 1, 2 and 3: 1-very unsatisfied 2-unsatisfied 3-neutral 4-satisfied 5-very satisfied

1. How satisfied are you with the comfort of your office furnishings (chair, desk, computer, equipment, etc.)? [note: calibration question]
2. How satisfied are you with the temperature in your workspace?
3. How satisfied are you with the air quality in your workspace (i.e. stuffy/stale air, cleanliness, odors)?

Scale for question 4 and 5: 1-interferes 2-somewhat interferes 3-neither 4-somewhat enhances 5-enhances

4. Does your thermal comfort in your workspace interfere with or enhance your ability to get your job done?
5. Does the air quality in your workspace interfere with or enhance your ability to get your job done?

Scale for question 6. 1-inefficient 2-somewhat inefficient 3-average 4-somewhat efficient 5-efficient

6. Considering energy use, how efficiently is this building performing in your opinion?

5.6 SAMPLING RESULTS

This subsection provides a detailed graphical summary of all sampling results. Data was collected continuously throughout the demonstration project.

5.6.1 Unreduced Data Samples

Shown here are samples of data spanning two or three days during the test period to graphically illustrate the results that were obtained. There are 8 graphs for each of the 3 demonstration sites, for a total of 24 graphs presented as follows. The data point color shading is keyed to the outdoor temperature; a brighter shade indicates warmer outdoor air temperature. The DX air conditioners units have two cooling circuits, which are designated in the charts as 1 or 2.

<u>Refrigerant Pressure Charts</u>

Two pressures are charted versus time. High pressure (HiPres) is the pressure at the liquid line between the condenser coil and the liquid-suction heat exchanger separator. High pressure increases with load and ambient temperature, and increased pressure means more compressor work and reduced energy efficiency. The EER Optimizer controller compensates by raising fan speed. Low Pressure (LoPres) is the pressure at the suction line between the evaporator coil and the compressor. Low pressure decreases as the EER Optimizer controller increases dehumidification. The compressor provides lift from low pressure to high pressure, and when the compressor is not energized the pressures tend to equalize – high pressure drops and low pressure jumps up.

[17] Standard survey questions can be reviewed at http://www.cbe.berkeley.edu/research/survey.htm

Refrigerant Temperature Charts

Two temperatures are charted versus time. High flow temperature (HiFlo) is the temperature of the liquid refrigerant flowing between the condenser coil and the liquid-suction heat exchanger separator. High flow temperature is used together with the saturated liquid pressure to calculate refrigerant subcooling, which EER Optimizer uses to detect faults and determine the optimal refrigerant charge level. Low flow temperature (LoFlo) is the temperature of the suction line between the evaporator and compressor. Low flow temperature is used together with the saturated suction pressure to calculate refrigerant superheat, which EER Optimizer uses to detect & diagnose faults.

Cooling and Power Charts

The amount of cooling being delivered and the amount of electric power being consumed by the air conditioner is charted versus time. At each demonstration site, a wall mounted thermostat calls for first stage cooling if the space temperature rises 1 degree above setpoint, and compressor #1 is energized. If the space temperature rises 2 degrees above setpoint, the thermostat calls for second stage cooling and compressor #2 is energized. The amount of cooling varies with outdoor temperature and load, while the EER Optimizer controller seeks maximum cooling for minimum power by adjusting fan speed, blower speed, and refrigerant charge level.

Air Temperature Charts

The temperature of the air entering the air-conditioner cooling coil (Entering Air Temperature - EAT), temperatures of the air leaving the cooling coil (Leaving Air Temperature - LAT), and temperature of the conditioned air supplied to the space (Supply Air Temperature - SAT) are charted versus time. EAT is a function of the space air temperature, fresh air temperature, and the heat pickup from the ductwork between / above the conditioned space to the air-conditioner unit. LAT and SAT are under EER Optimizer control to simultaneously meet the sensible load / thermostat space temperature setpoint and the latent load / space humidity setpoint range.

Humidity and Fan Speed Charts

Entering air humidity is charted along with the blower / evaporator fan speed (EFS) and condenser fan speed (CFS), which are both under EER Optimizer control. Operating parameters are optimized for dehumidification as needed to meet the humidity set point limit, which is $50\%_{rh}$ at CCAFS, $55\%_{rh}$ at MCASB, and $45\%_{rh}$ at Fort Irwin. Blower and fan speed are controlled along with damper positions to minimize electric usage while providing the maximum sensible cooling, and enough latent cooling to meet the humidity set point limit.

Sensible Heat Ratio Charts

Sensible heat ratio is the amount of sensible cooling relative to the total quantity of cooling being provided, which is under the control of the EER Optimizer system. Sensible cooling provides a decrease in temperature, while latent cooling provides a decrease in absolute humidity. The sum of sensible cooling plus latent cooling is the total quantity of cooling. A sensible heat ratio of 1.0 means no dehumidification is being provided, as seen at Fort Irwin, which is in the Mojave Desert with very low outdoor humidity and no need for dehumidification. The chart for MCASB shows sensible heat ratio varying between 0.7 and 1.0 as the system adjusts to meet the dehumidification need of the space. The chart for CCAFS shows a sensible heat ratio between 0.6 and 0.7, lower because of the much higher outdoor humidity at the Florida seacoast.

5.6.2 Fault Detection & Diagnostics

Shown are sample fault detection screens for the DX air conditioner unit at each demonstration site. The EER Optimizer system successfully detected numerous problems such as fouled or deteriorated condenser coil, high humidity, potential diffuser dripping, low refrigerant, and coil freezing. Faults are emailed to a project engineer as they occur; an example email is shown below.

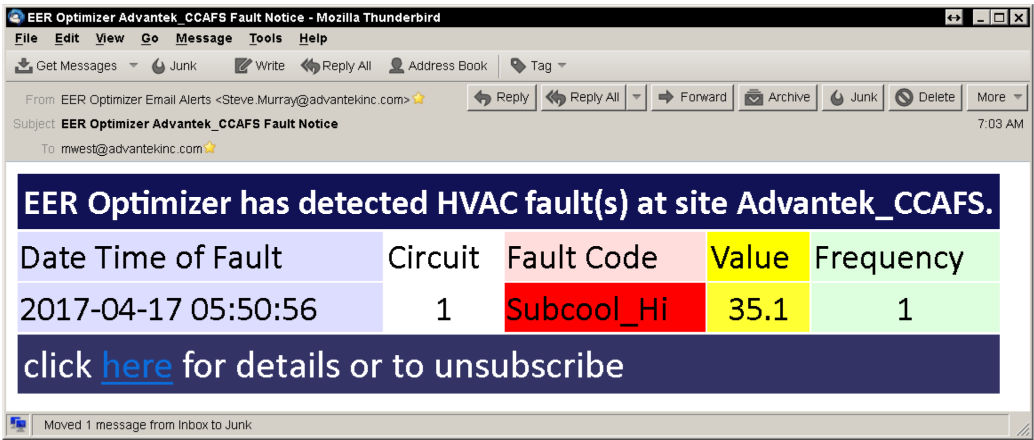


Figure 22. Fault Detection & Diagnostic Email Alert.

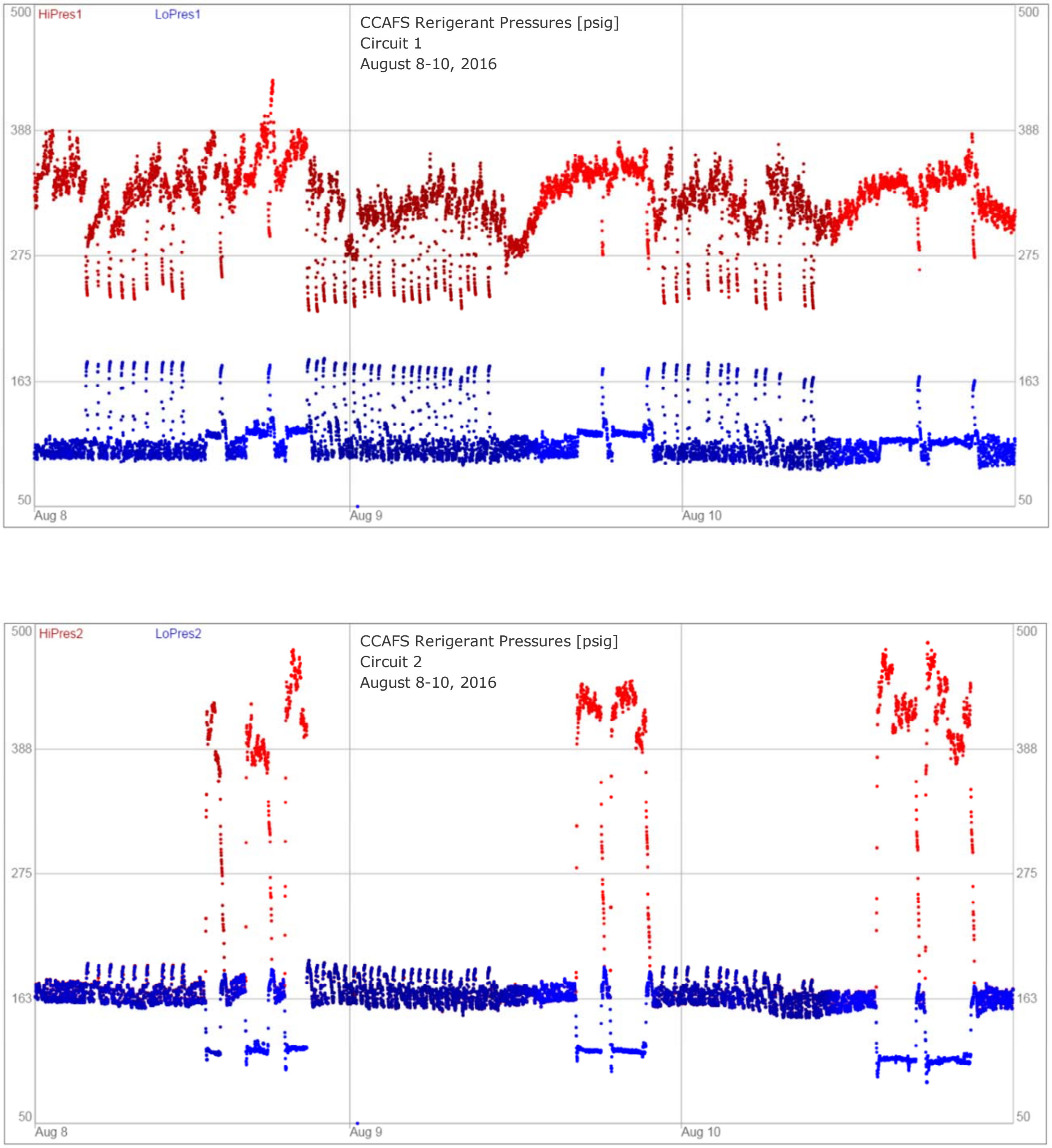


Figure 23. CCAFS DX Unit R410A Refrigerant Pressure versus Time for Circuit 1 (top) and Circuit 2 (bottom).

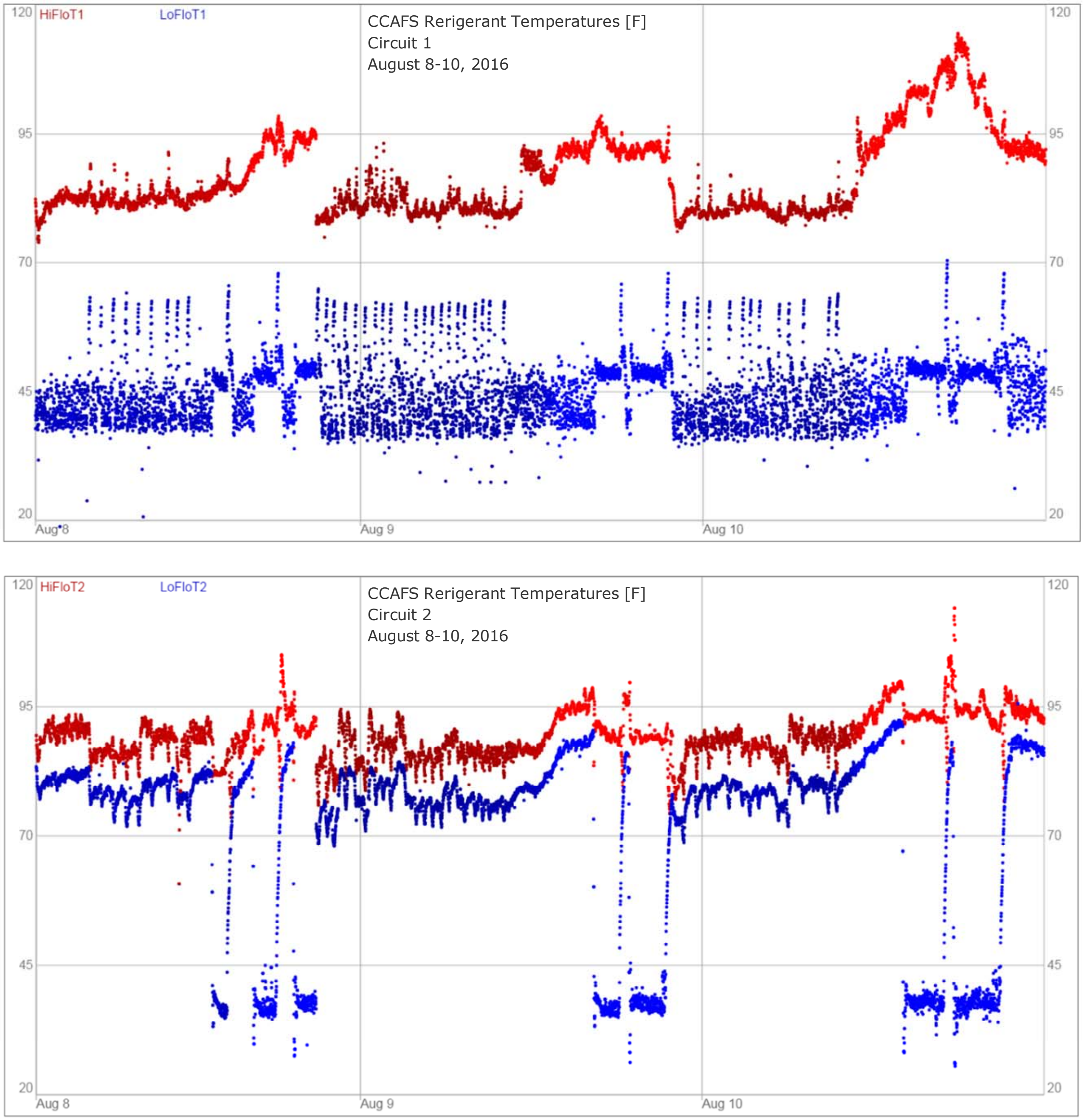


Figure 24. CCAFS DX Unit R410A Refrigerant Temperature versus Time for Circuit 1 (top) and Circuit 2 (bottom).

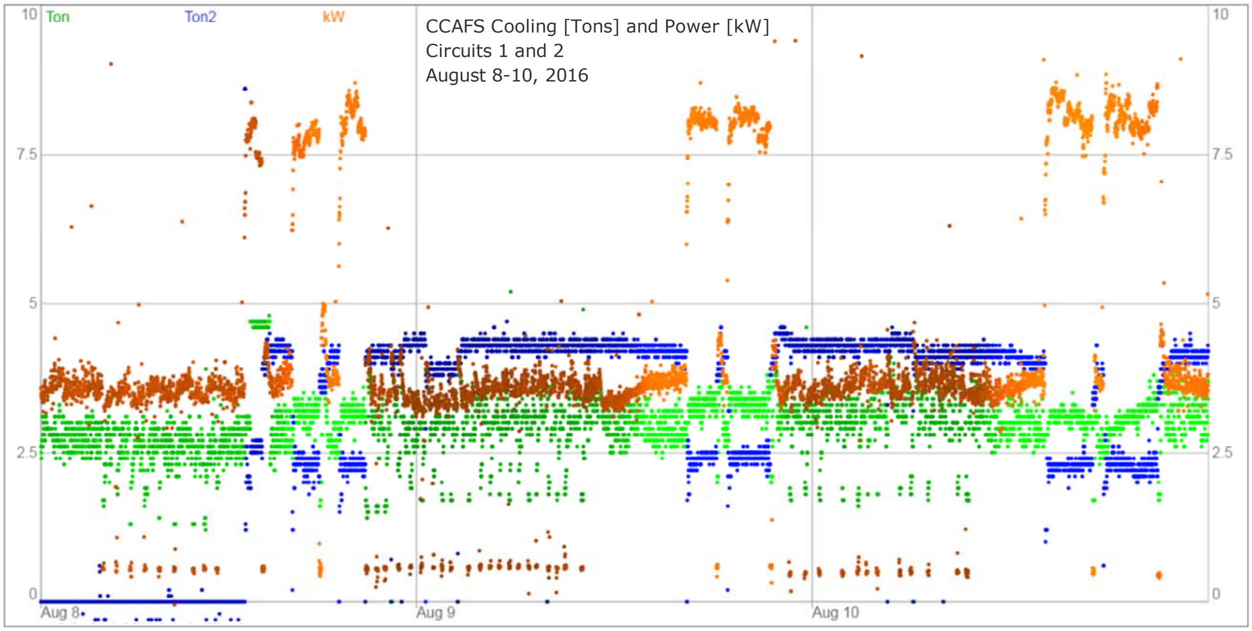


Figure 25. **CCAFS Total Cooling Delivered by Each Circuit and Power Demand versus Time.**

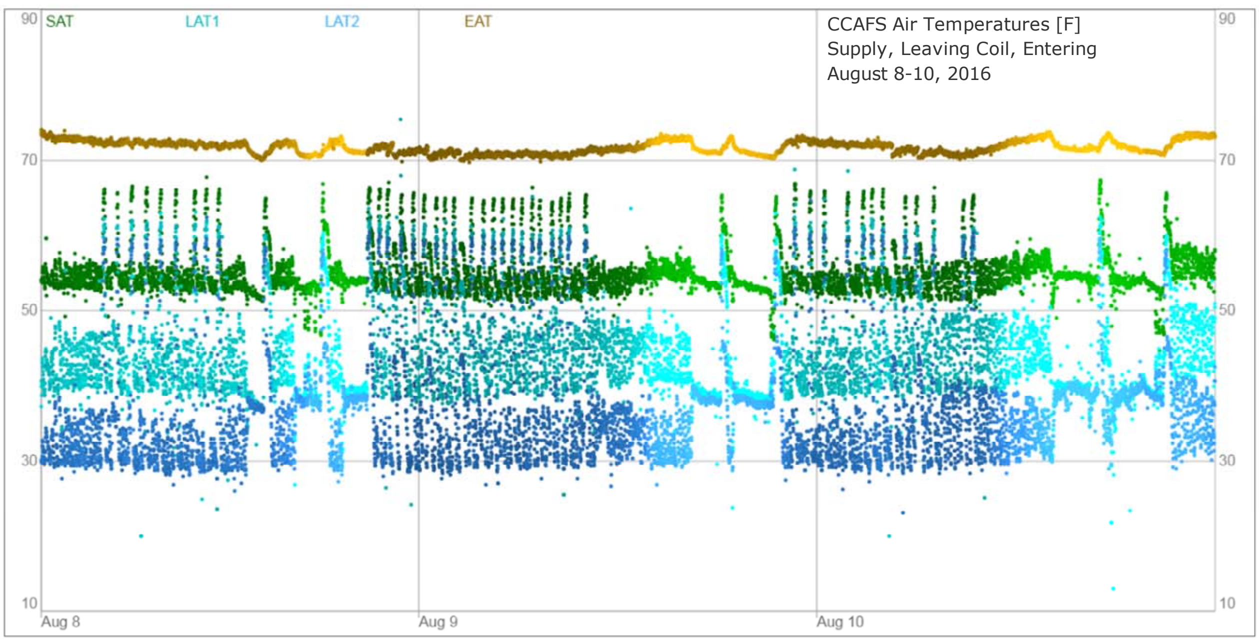


Figure 26. **CCAFS Air Temperatures – Supply, Leaving Coil, and Entering Air versus Time.**

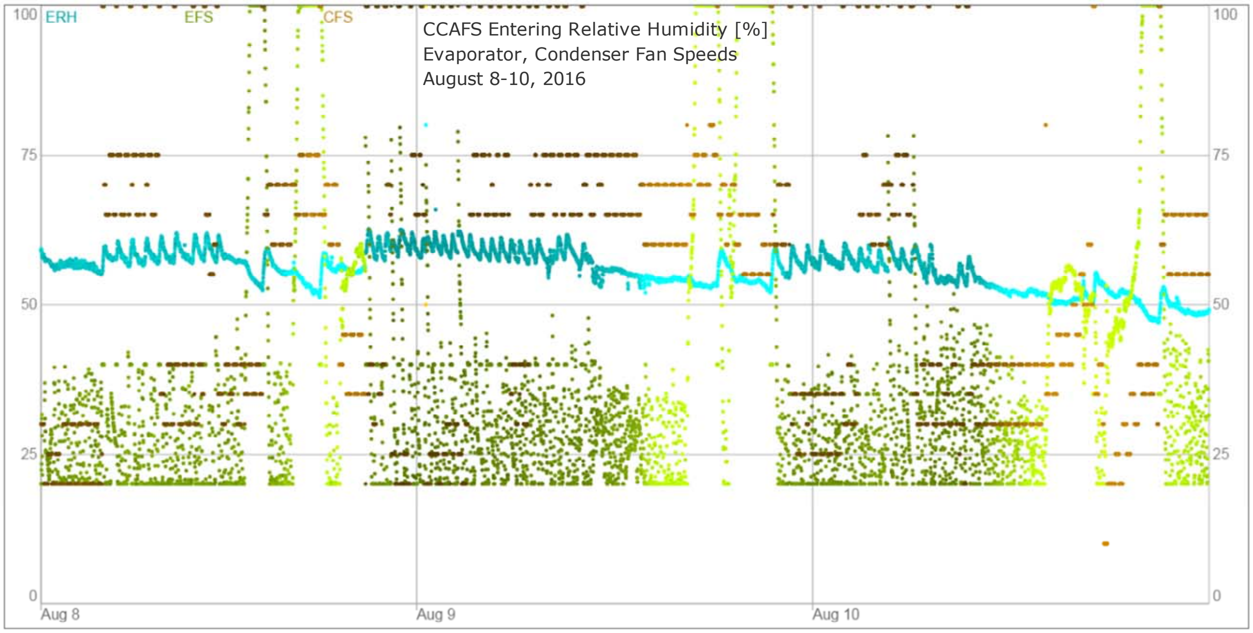


Figure 27. **CCAFS Relative Humidity of Air Entering Air Conditioner Cooling Coil Long with Evaporator and Condenser Fan Speeds versus Time.**

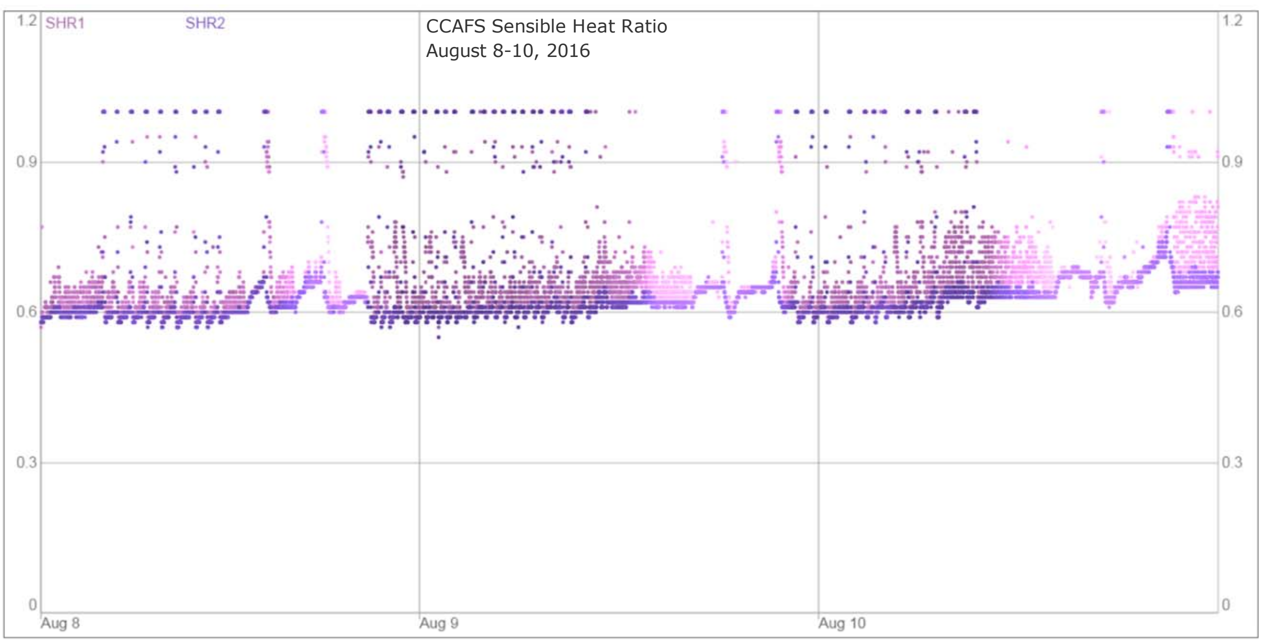
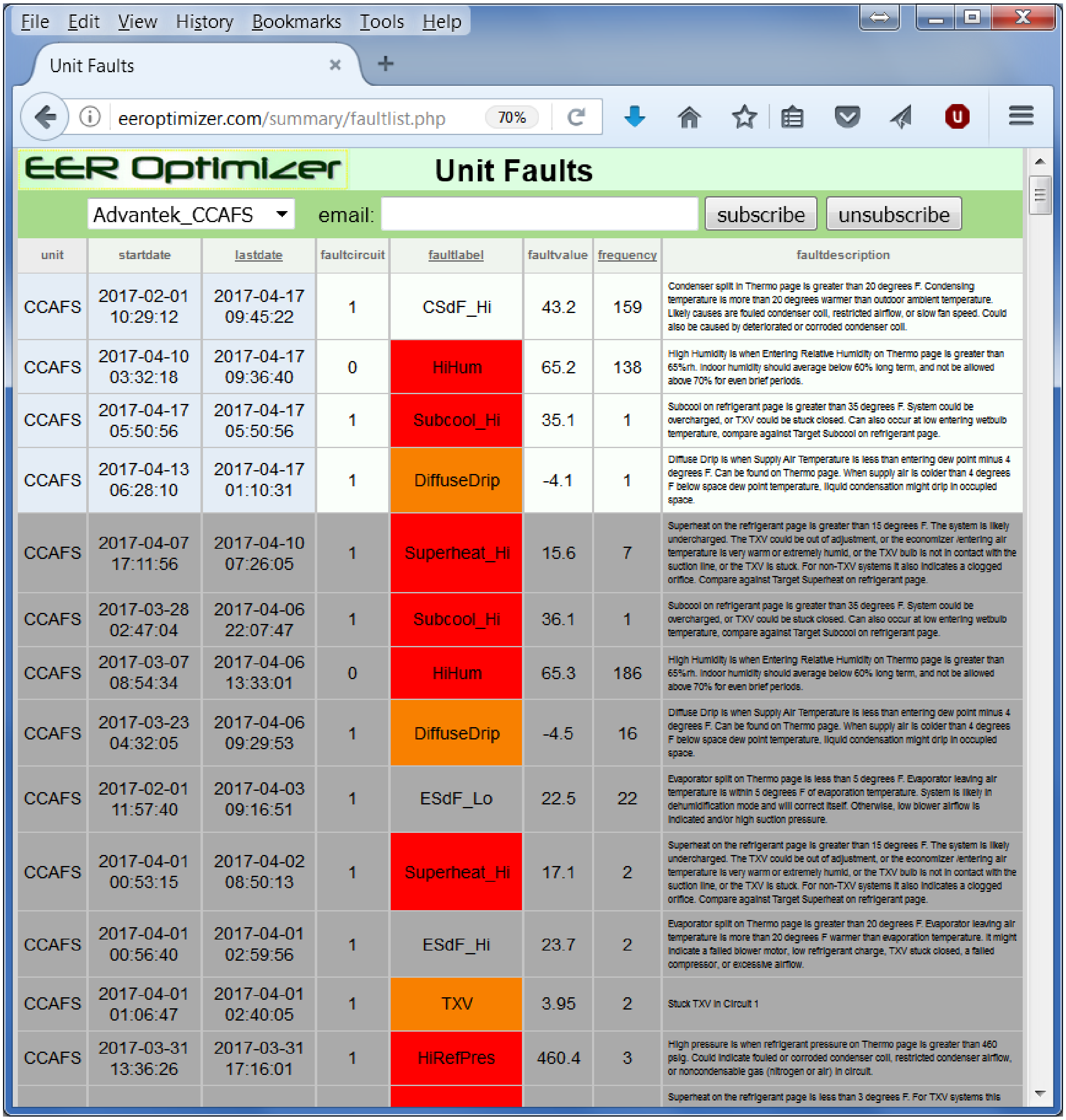


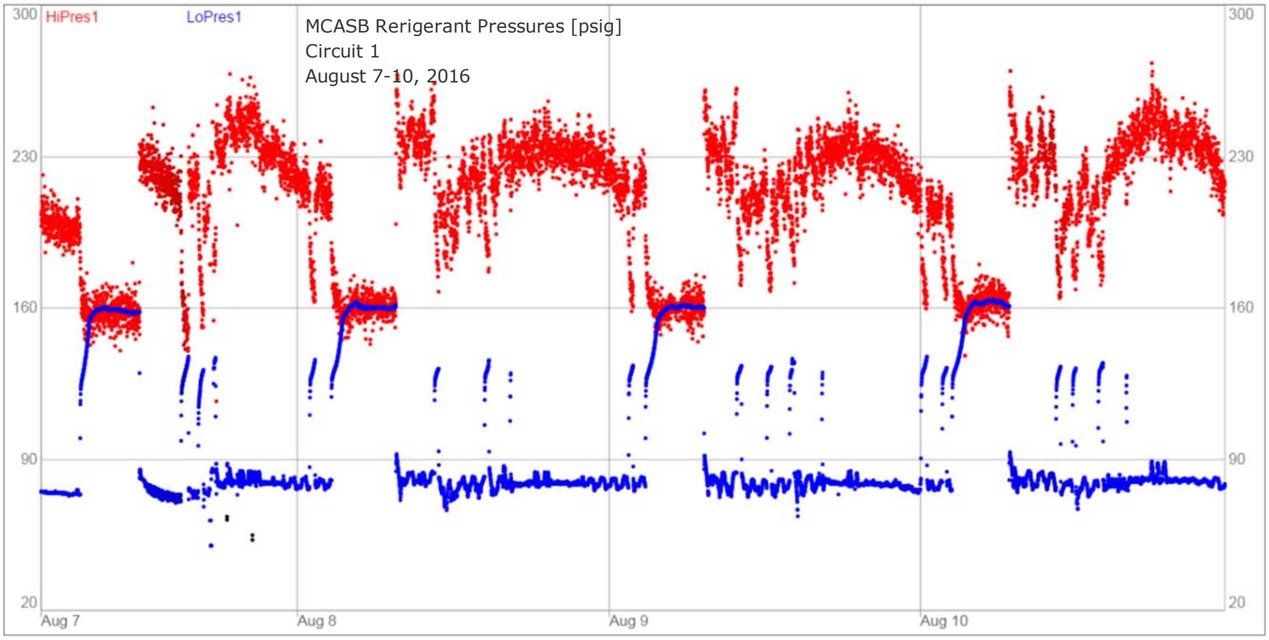
Figure 28. **CCAFS Sensible Heat Ratio versus Time.**



unit	startdate	lastdate	faultcircuit	faultlabel	faultvalue	frequency	faultdescription
CCAFS	2017-02-01 10:29:12	2017-04-17 09:45:22	1	CSdF_Hi	43.2	159	Condenser split in Thermo page is greater than 20 degrees F. Condensing temperature is more than 20 degrees warmer than outdoor ambient temperature. Likely causes are fouled condenser coil, restricted airflow, or slow fan speed. Could also be caused by deteriorated or corroded condenser coil.
CCAFS	2017-04-10 03:32:18	2017-04-17 09:36:40	0	HiHum	65.2	138	High Humidity is when Entering Relative Humidity on Thermo page is greater than 65%rh. Indoor humidity should average below 60% long term, and not be allowed above 70% for even brief periods.
CCAFS	2017-04-17 05:50:56	2017-04-17 05:50:56	1	Subcool_Hi	35.1	1	Subcool on refrigerant page is greater than 35 degrees F. System could be overcharged, or TXV could be stuck closed. Can also occur at low entering wetbulb temperature, compare against Target Subcool on refrigerant page.
CCAFS	2017-04-13 06:28:10	2017-04-17 01:10:31	1	DiffuseDrip	-4.1	1	Diffuse Drip is when Supply Air Temperature is less than entering dew point minus 4 degrees F. Can be found on Thermo page. When supply air is colder than 4 degrees F below space dew point temperature, liquid condensation might drip in occupied space.
CCAFS	2017-04-07 17:11:56	2017-04-10 07:26:05	1	Superheat_Hi	15.6	7	Superheat on the refrigerant page is greater than 15 degrees F. The system is likely undercharged. The TXV could be out of adjustment, or the economizer /entering air temperature is very warm or extremely humid, or the TXV bulb is not in contact with the suction line, or the TXV is stuck. For non-TXV systems it also indicates a clogged orifice. Compare against Target Superheat on refrigerant page.
CCAFS	2017-03-28 02:47:04	2017-04-06 22:07:47	1	Subcool_Hi	36.1	1	Subcool on refrigerant page is greater than 35 degrees F. System could be overcharged, or TXV could be stuck closed. Can also occur at low entering wetbulb temperature, compare against Target Subcool on refrigerant page.
CCAFS	2017-03-07 08:54:34	2017-04-06 13:33:01	0	HiHum	65.3	186	High Humidity is when Entering Relative Humidity on Thermo page is greater than 65%rh. Indoor humidity should average below 60% long term, and not be allowed above 70% for even brief periods.
CCAFS	2017-03-23 04:32:05	2017-04-06 09:29:53	1	DiffuseDrip	-4.5	16	Diffuse Drip is when Supply Air Temperature is less than entering dew point minus 4 degrees F. Can be found on Thermo page. When supply air is colder than 4 degrees F below space dew point temperature, liquid condensation might drip in occupied space.
CCAFS	2017-02-01 11:57:40	2017-04-03 09:16:51	1	ESdF_Lo	22.5	22	Evaporator split on Thermo page is less than 5 degrees F. Evaporator leaving air temperature is within 5 degrees F of evaporation temperature. System is likely in dehumidification mode and will correct itself. Otherwise, low blower airflow is indicated and/or high suction pressure.
CCAFS	2017-04-01 00:53:15	2017-04-02 08:50:13	1	Superheat_Hi	17.1	2	Superheat on the refrigerant page is greater than 15 degrees F. The system is likely undercharged. The TXV could be out of adjustment, or the economizer /entering air temperature is very warm or extremely humid, or the TXV bulb is not in contact with the suction line, or the TXV is stuck. For non-TXV systems it also indicates a clogged orifice. Compare against Target Superheat on refrigerant page.
CCAFS	2017-04-01 00:56:40	2017-04-01 02:59:56	1	ESdF_Hi	23.7	2	Evaporator split on Thermo page is greater than 20 degrees F. Evaporator leaving air temperature is more than 20 degrees F warmer than evaporation temperature. It might indicate a failed blower motor, low refrigerant charge, TXV stuck closed, a failed compressor, or excessive airflow.
CCAFS	2017-04-01 01:06:47	2017-04-01 02:40:05	1	TXV	3.95	2	Stuck TXV in Circuit 1
CCAFS	2017-03-31 13:36:26	2017-03-31 17:16:01	1	HiRefPres	460.4	3	High pressure is when refrigerant pressure on Thermo page is greater than 460 psig. Could indicate fouled or corroded condenser coil, restricted condenser airflow, or noncondensable gas (nitrogen or air) in circuit.
							Superheat on the refrigerant page is less than 3 degrees F. For TXV systems this

Figure 29. CCAFS Fault Detection & Diagnostics Screen Shows the Fault CSdF_Hi Has Occurred 159 Times Between February 1 and April 17, 2017.

The current faults value 43.2 degrees-F is consistent with the deteriorated condition of the condenser coil on this unit. A replacement condenser coil has been ordered.



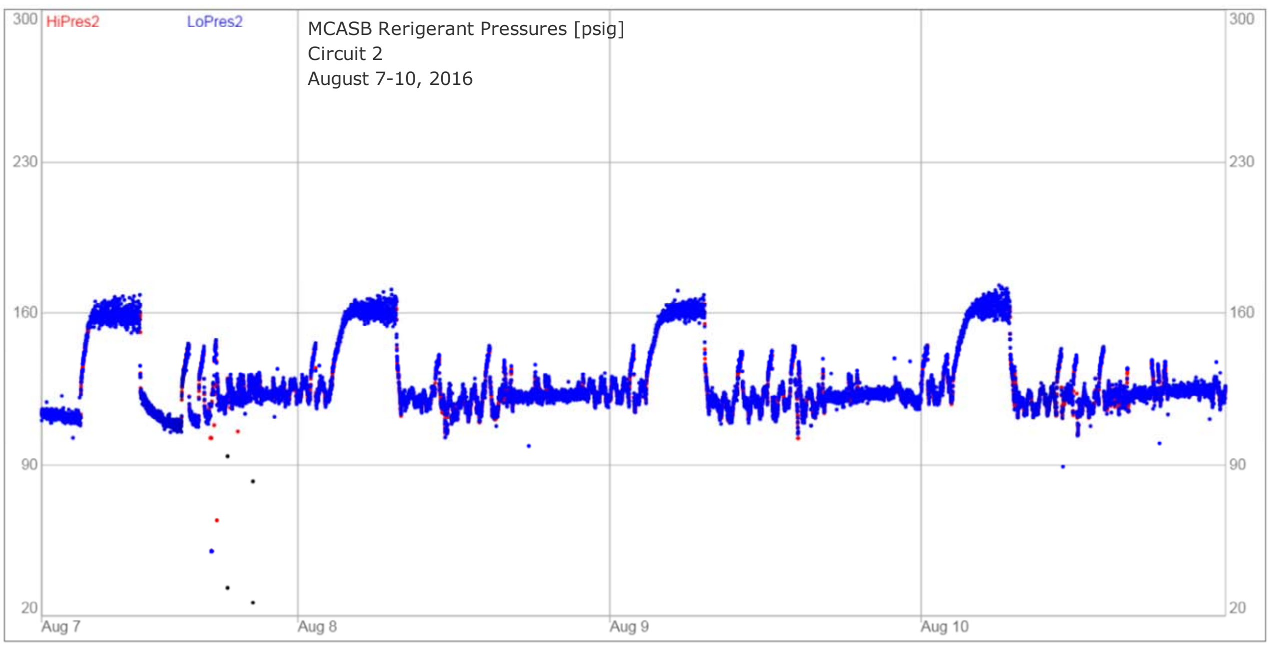
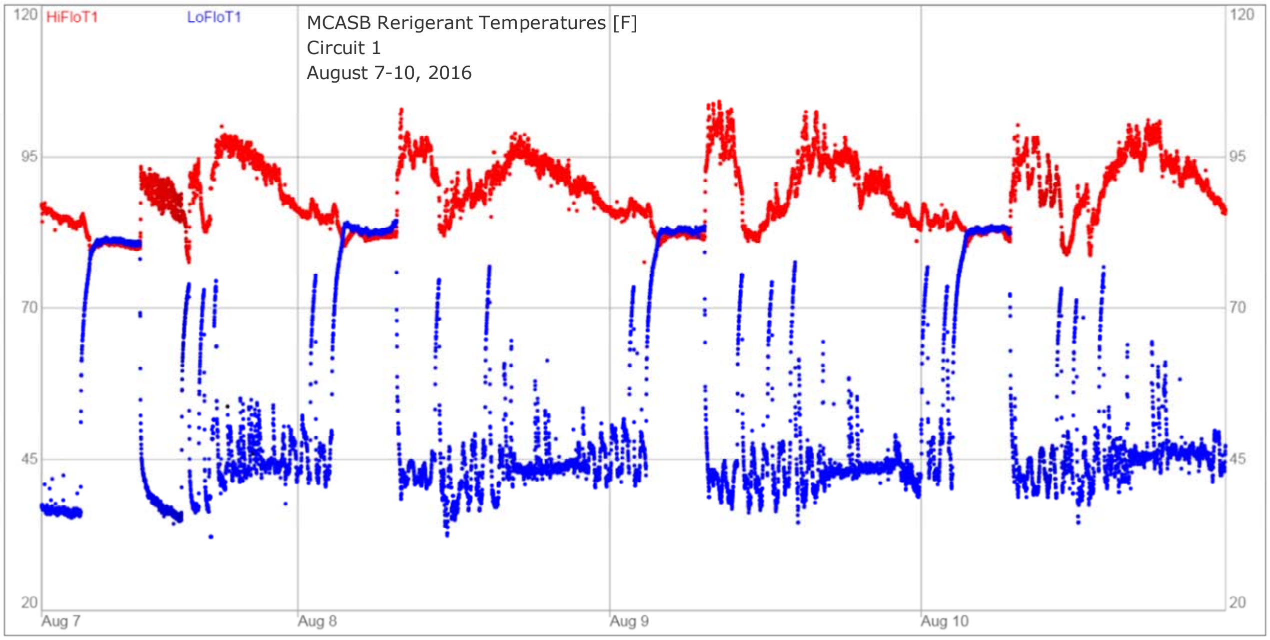


Figure 30. MCASB DX Unit R22 Refrigerant Pressure versus Time for Circuit 1 (top) and Circuit 2 (bottom).



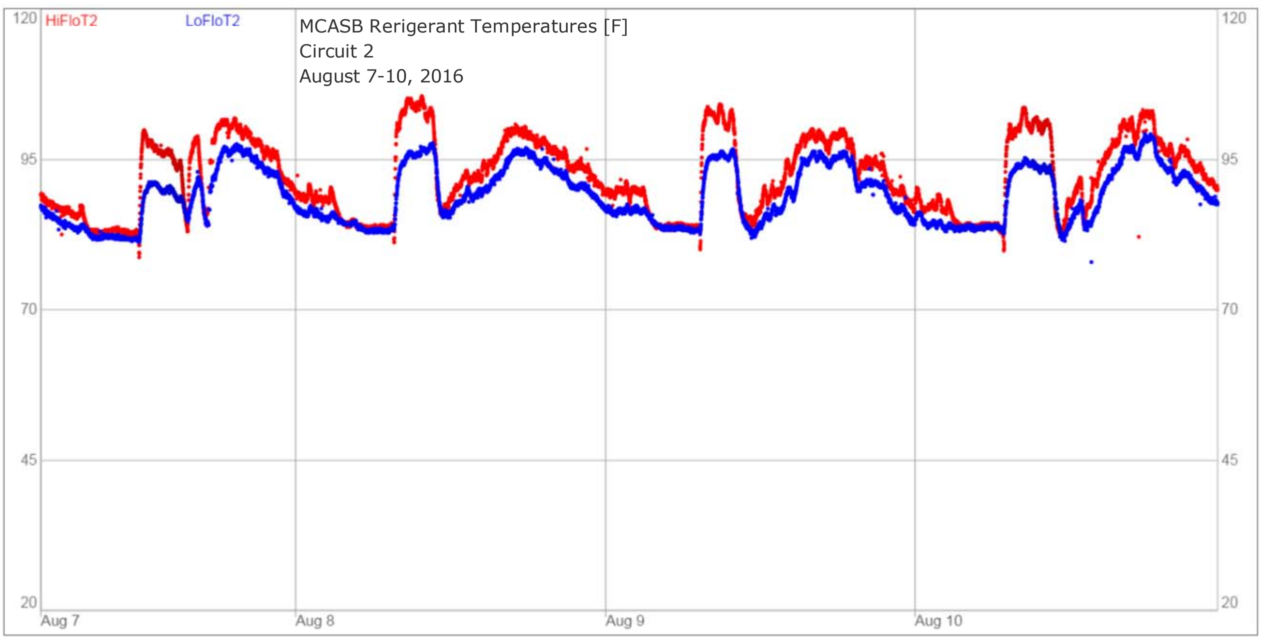


Figure 31. MCASB DX Unit R22 Refrigerant Temperature versus Time for Circuit 1 (top) and Circuit 2 (bottom).

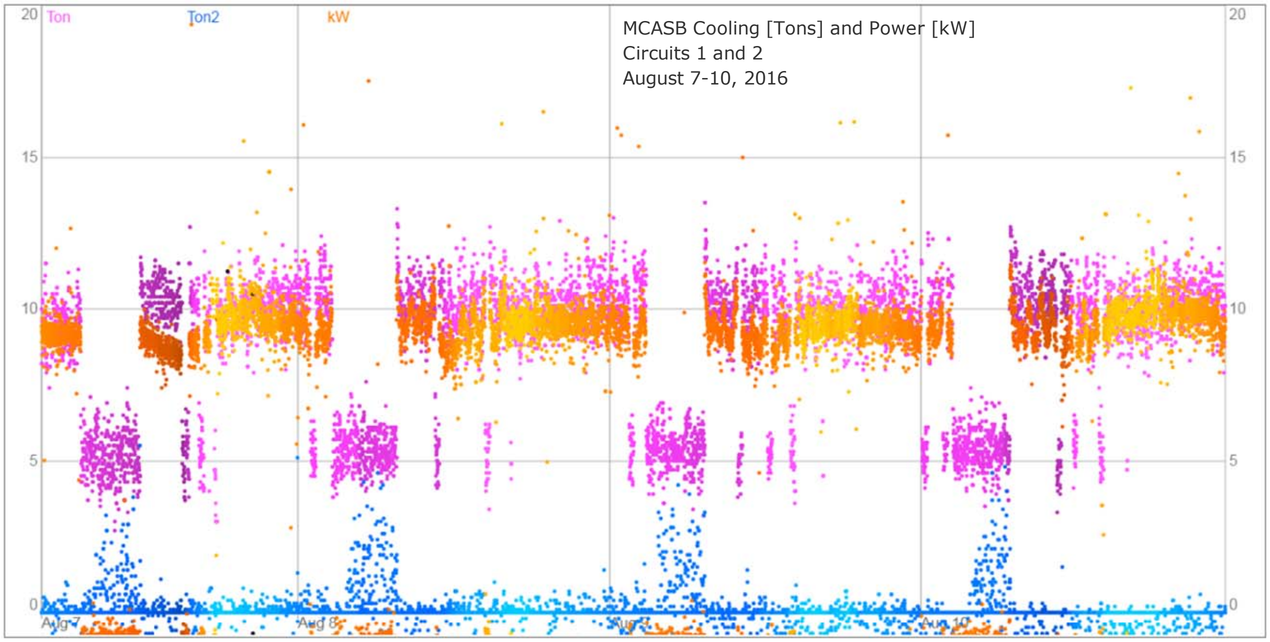


Figure 32. MCASB Total Cooling delivered by Each Circuit and Power Demand versus Time.

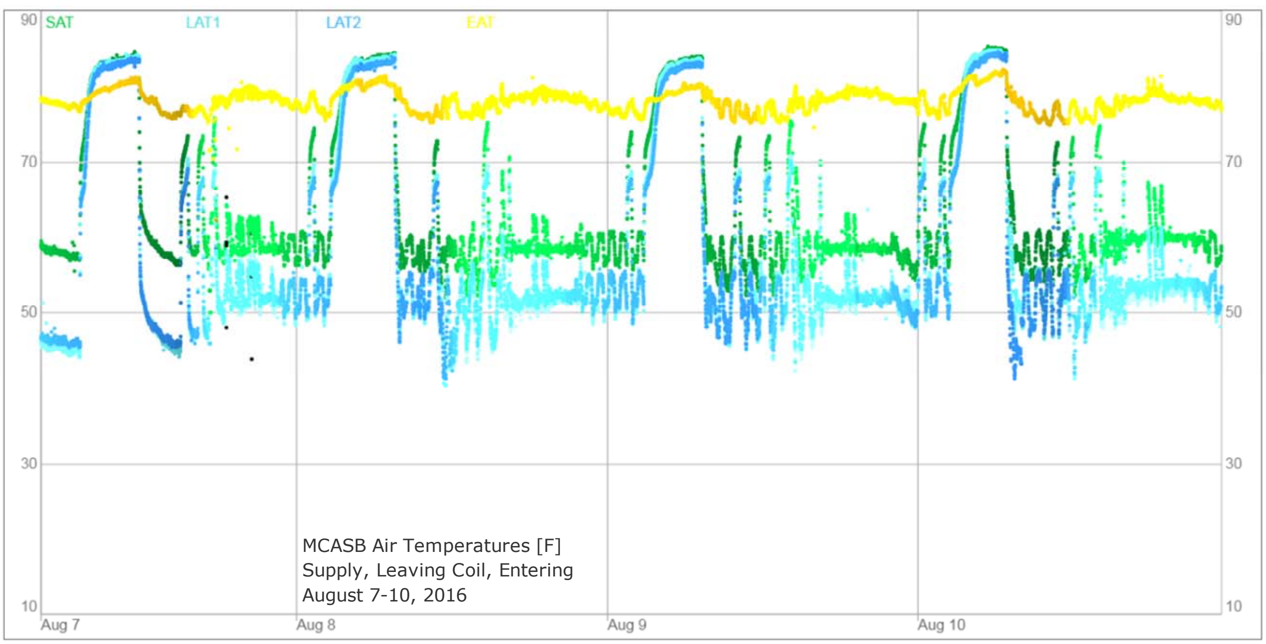


Figure 33. MCASB Air Temperatures – Supply, Leaving Coil, and Entering Air versus Time.

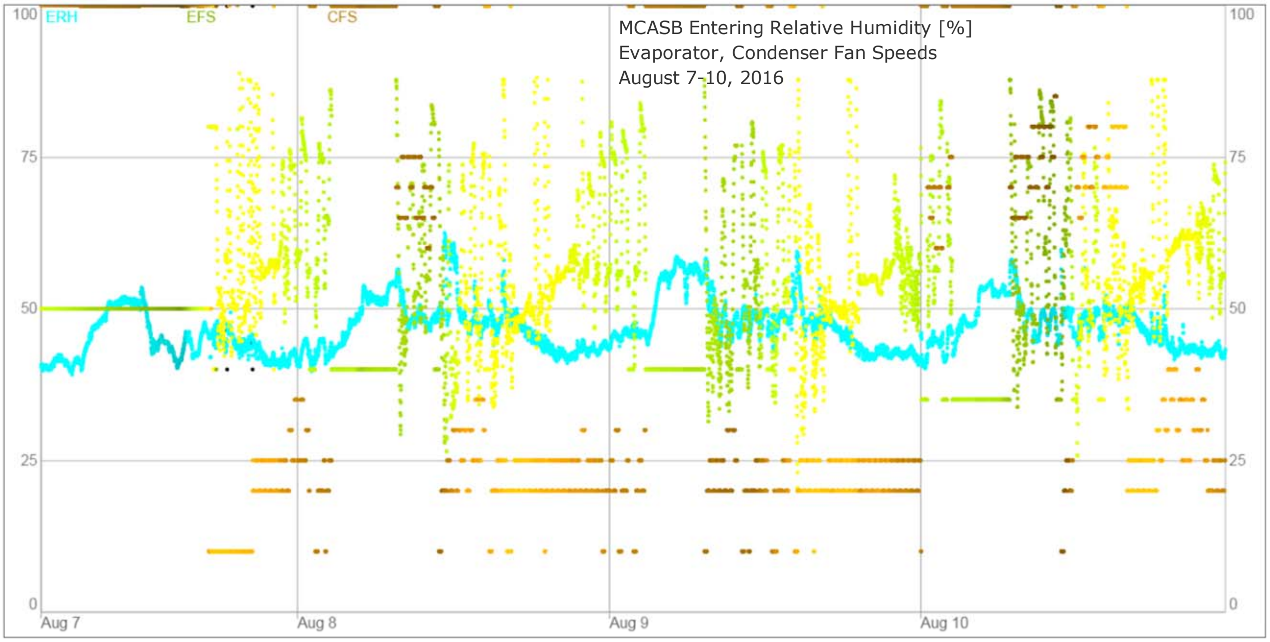


Figure 34. MCASB Relative Humidity of Air Entering Air Conditioner Cooling Coil Long with Evaporator and Condenser Fan Speeds versus Time.

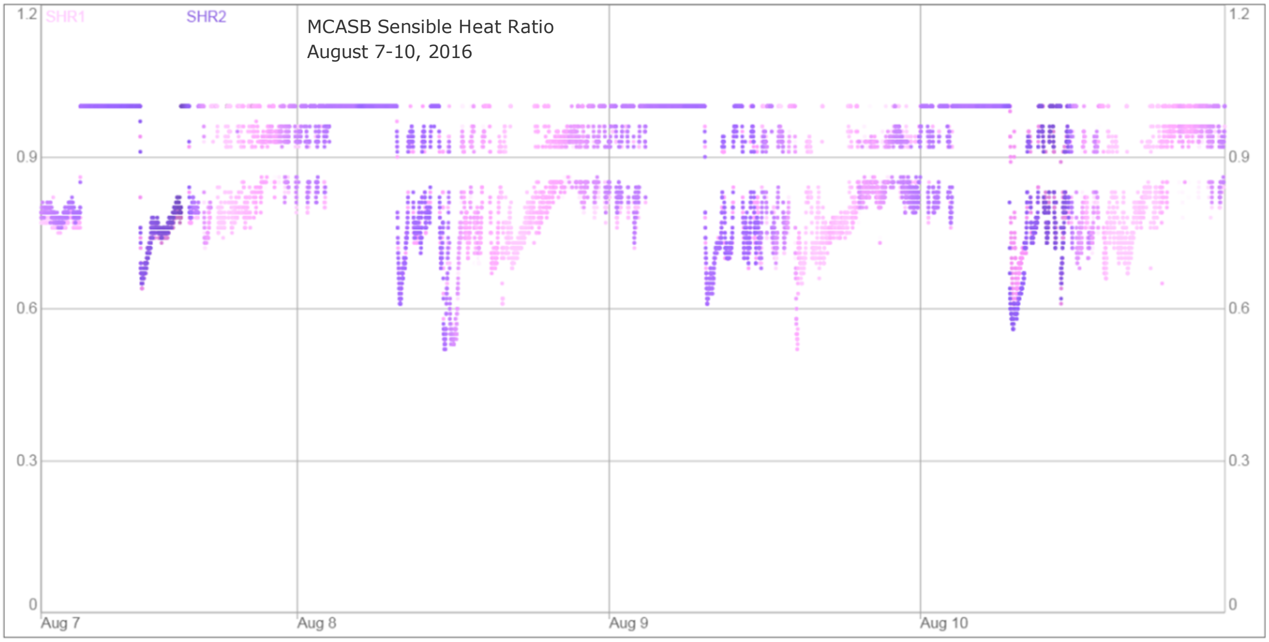
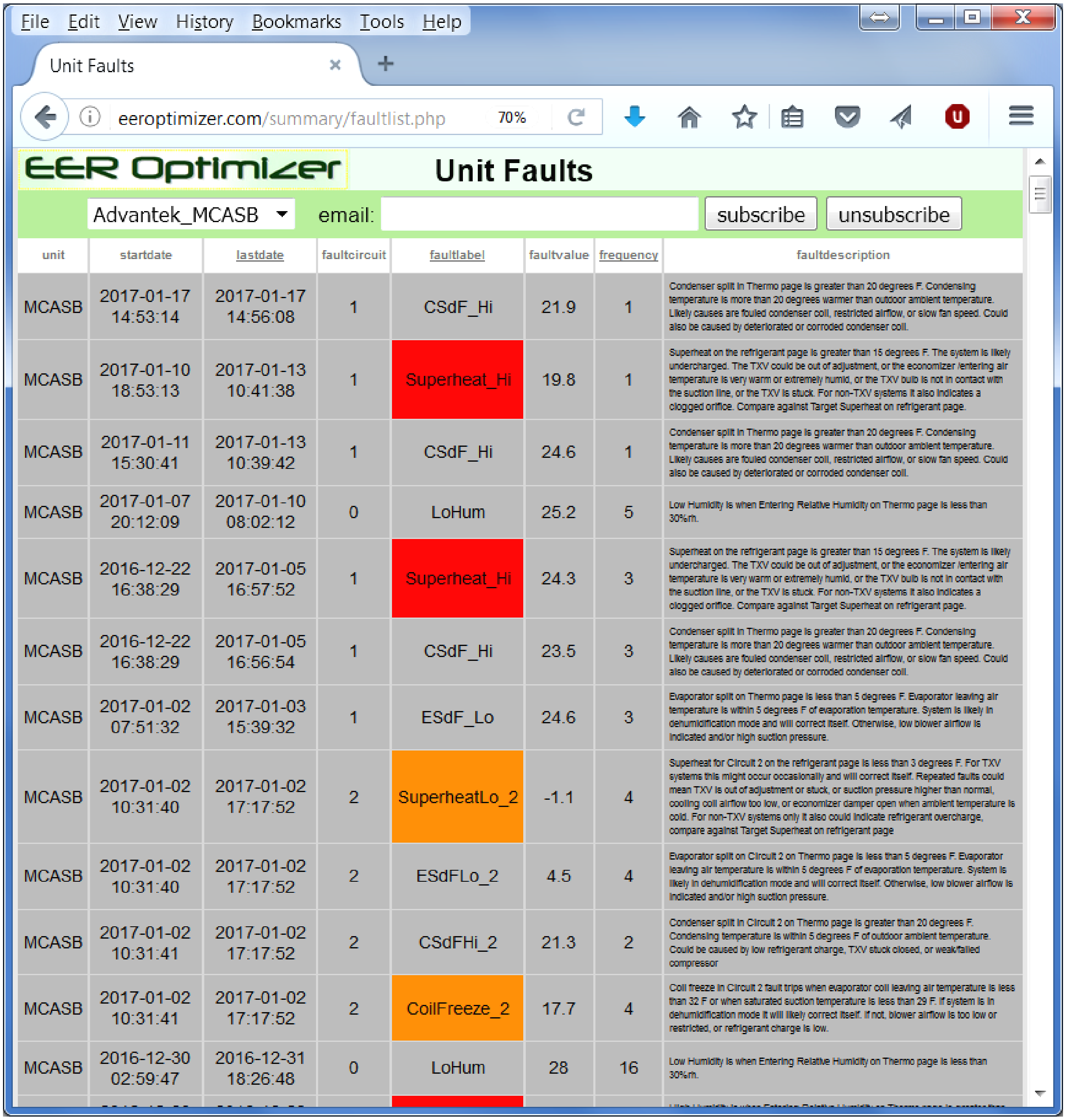


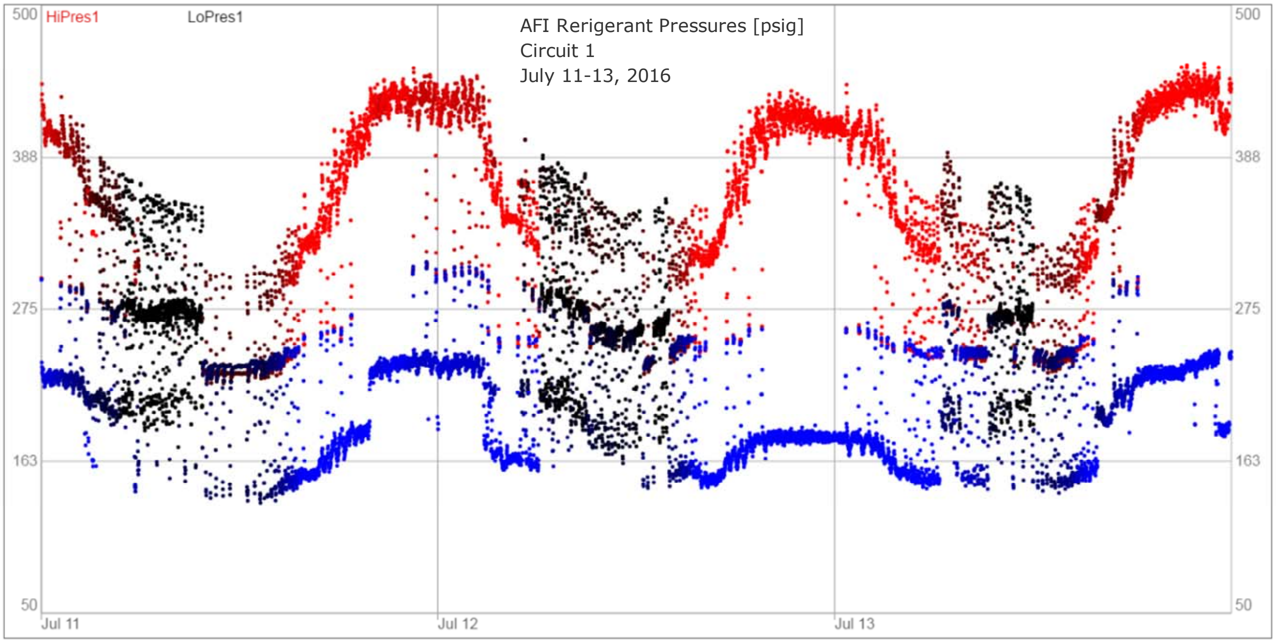
Figure 35. MCASB Sensible Heat Ratio versus Time.



unit	startdate	lastdate	faultcircuit	faultlabel	faultvalue	frequency	faultdescription
MCASB	2017-01-17 14:53:14	2017-01-17 14:56:08	1	CSdF_Hi	21.9	1	Condenser split in Thermo page is greater than 20 degrees F. Condensing temperature is more than 20 degrees warmer than outdoor ambient temperature. Likely causes are fouled condenser coil, restricted airflow, or slow fan speed. Could also be caused by deteriorated or corroded condenser coil.
MCASB	2017-01-10 18:53:13	2017-01-13 10:41:38	1	Superheat_Hi	19.8	1	Superheat on the refrigerant page is greater than 15 degrees F. The system is likely undercharged. The TXV could be out of adjustment, or the economizer /entering air temperature is very warm or extremely humid, or the TXV bulb is not in contact with the suction line, or the TXV is stuck. For non-TXV systems it also indicates a clogged orifice. Compare against Target Superheat on refrigerant page.
MCASB	2017-01-11 15:30:41	2017-01-13 10:39:42	1	CSdF_Hi	24.6	1	Condenser split in Thermo page is greater than 20 degrees F. Condensing temperature is more than 20 degrees warmer than outdoor ambient temperature. Likely causes are fouled condenser coil, restricted airflow, or slow fan speed. Could also be caused by deteriorated or corroded condenser coil.
MCASB	2017-01-07 20:12:09	2017-01-10 08:02:12	0	LoHum	25.2	5	Low Humidity is when Entering Relative Humidity on Thermo page is less than 30%rh.
MCASB	2016-12-22 16:38:29	2017-01-05 16:57:52	1	Superheat_Hi	24.3	3	Superheat on the refrigerant page is greater than 15 degrees F. The system is likely undercharged. The TXV could be out of adjustment, or the economizer /entering air temperature is very warm or extremely humid, or the TXV bulb is not in contact with the suction line, or the TXV is stuck. For non-TXV systems it also indicates a clogged orifice. Compare against Target Superheat on refrigerant page.
MCASB	2016-12-22 16:38:29	2017-01-05 16:56:54	1	CSdF_Hi	23.5	3	Condenser split in Thermo page is greater than 20 degrees F. Condensing temperature is more than 20 degrees warmer than outdoor ambient temperature. Likely causes are fouled condenser coil, restricted airflow, or slow fan speed. Could also be caused by deteriorated or corroded condenser coil.
MCASB	2017-01-02 07:51:32	2017-01-03 15:39:32	1	ESdF_Lo	24.6	3	Evaporator split on Thermo page is less than 5 degrees F. Evaporator leaving air temperature is within 5 degrees F of evaporation temperature. System is likely in dehumidification mode and will correct itself. Otherwise, low blower airflow is indicated and/or high suction pressure.
MCASB	2017-01-02 10:31:40	2017-01-02 17:17:52	2	SuperheatLo_2	-1.1	4	Superheat for Circuit 2 on the refrigerant page is less than 3 degrees F. For TXV systems this might occur occasionally and will correct itself. Repeated faults could mean TXV is out of adjustment or stuck, or suction pressure higher than normal, cooling coil airflow too low, or economizer damper open when ambient temperature is cold. For non-TXV systems only it also could indicate refrigerant overcharge, compare against Target Superheat on refrigerant page
MCASB	2017-01-02 10:31:40	2017-01-02 17:17:52	2	ESdFLo_2	4.5	4	Evaporator split on Circuit 2 on Thermo page is less than 5 degrees F. Evaporator leaving air temperature is within 5 degrees F of evaporation temperature. System is likely in dehumidification mode and will correct itself. Otherwise, low blower airflow is indicated and/or high suction pressure.
MCASB	2017-01-02 10:31:41	2017-01-02 17:17:52	2	CSdFHi_2	21.3	2	Condenser split in Circuit 2 on Thermo page is greater than 20 degrees F. Condensing temperature is within 5 degrees F of outdoor ambient temperature. Could be caused by low refrigerant charge, TXV stuck closed, or weak/failed compressor
MCASB	2017-01-02 10:31:41	2017-01-02 17:17:52	2	CoilFreeze_2	17.7	4	Coil freeze in Circuit 2 fault trips when evaporator coil leaving air temperature is less than 32 F or when saturated suction temperature is less than 29 F. If system is in dehumidification mode it will likely correct itself. If not, blower airflow is too low or restricted, or refrigerant charge is low.
MCASB	2016-12-30 02:59:47	2016-12-31 18:26:48	0	LoHum	28	16	Low Humidity is when Entering Relative Humidity on Thermo page is less than 30%rh.

Figure 36. MCASB Fault Detection & Diagnostics Screen Shows a Fault CSdF_Hi on January 17, 2017.

The current faults value 21.9 degrees-F is consistent with the fouled condition of the condenser coil on this unit.



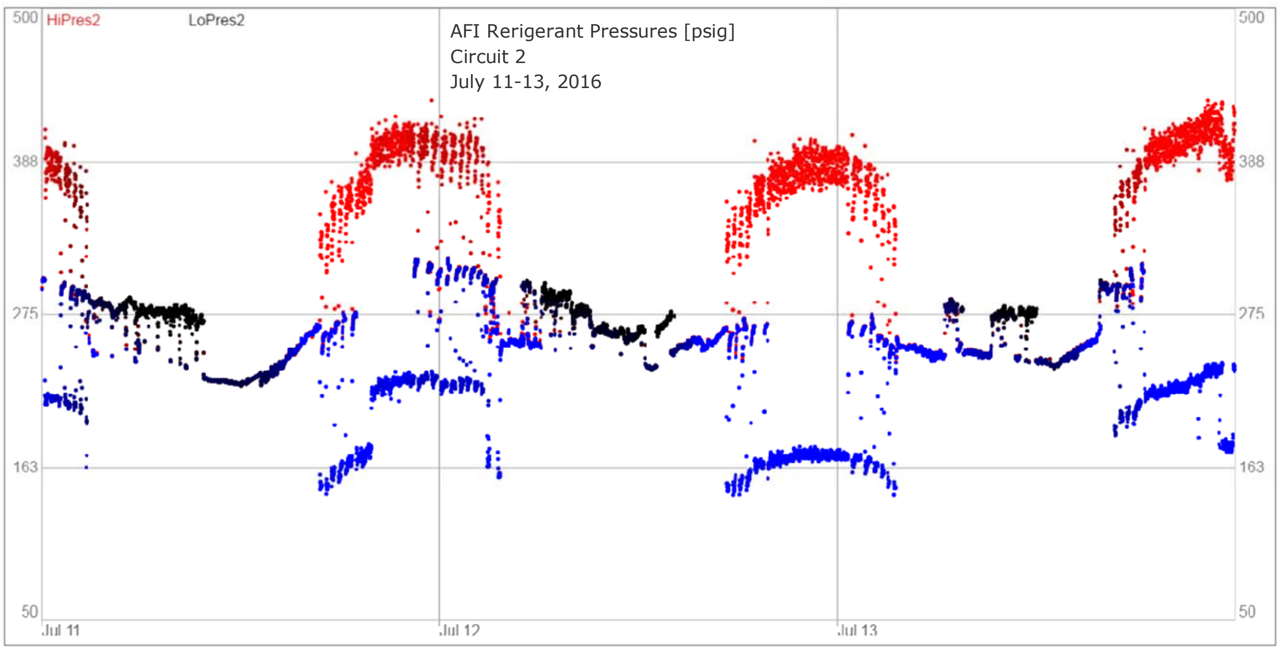


Figure 37. Fort Iwin DX Unit R410A Refrigerant Pressure versus Time for Circuit 1 (top) and Circuit 2 (bottom)

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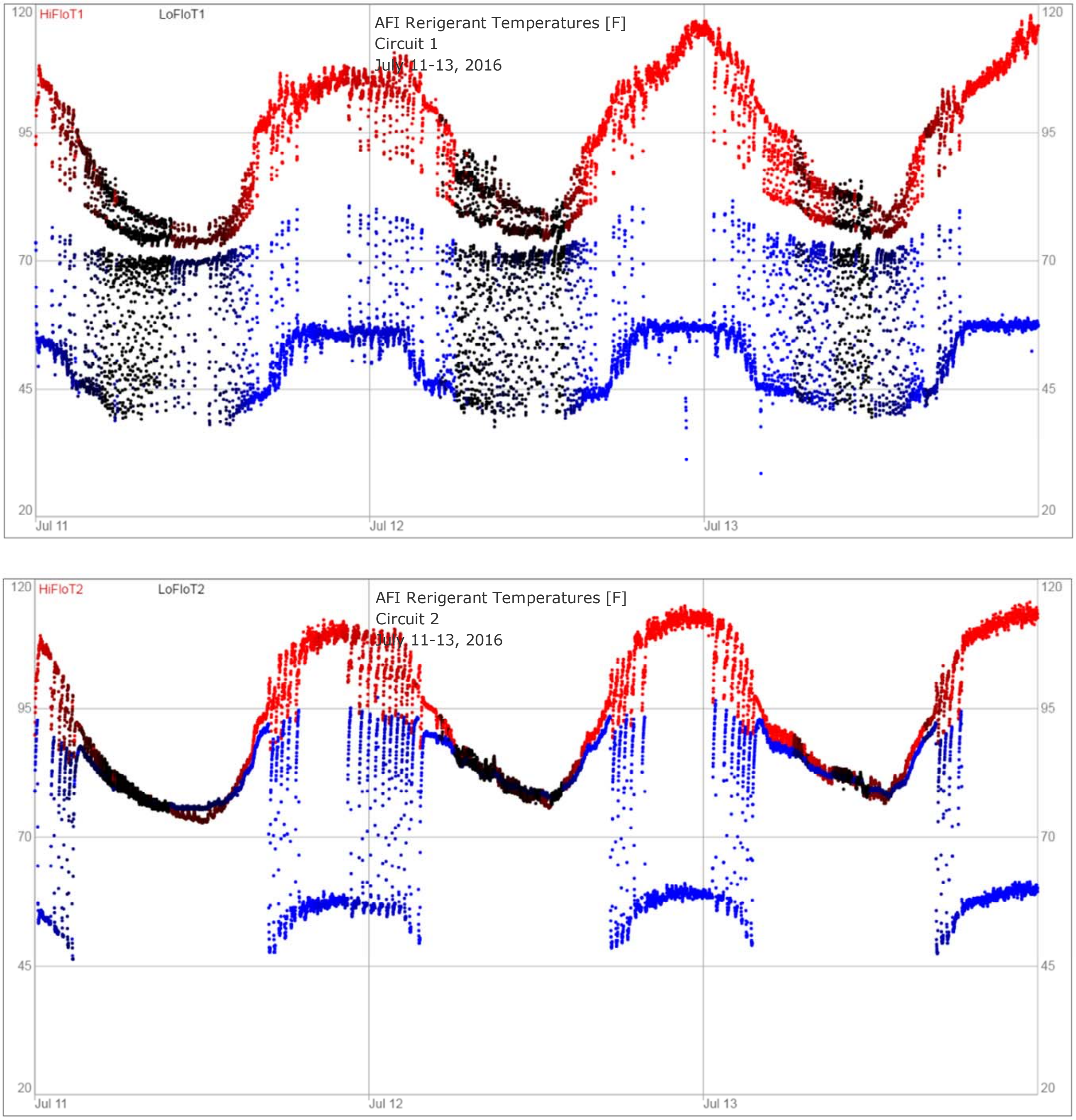


Figure 38. Fort Iwin DX Unit R410A Refrigerant Temperature versus Time for Circuit 1 (top) and Circuit 2 (bottom).

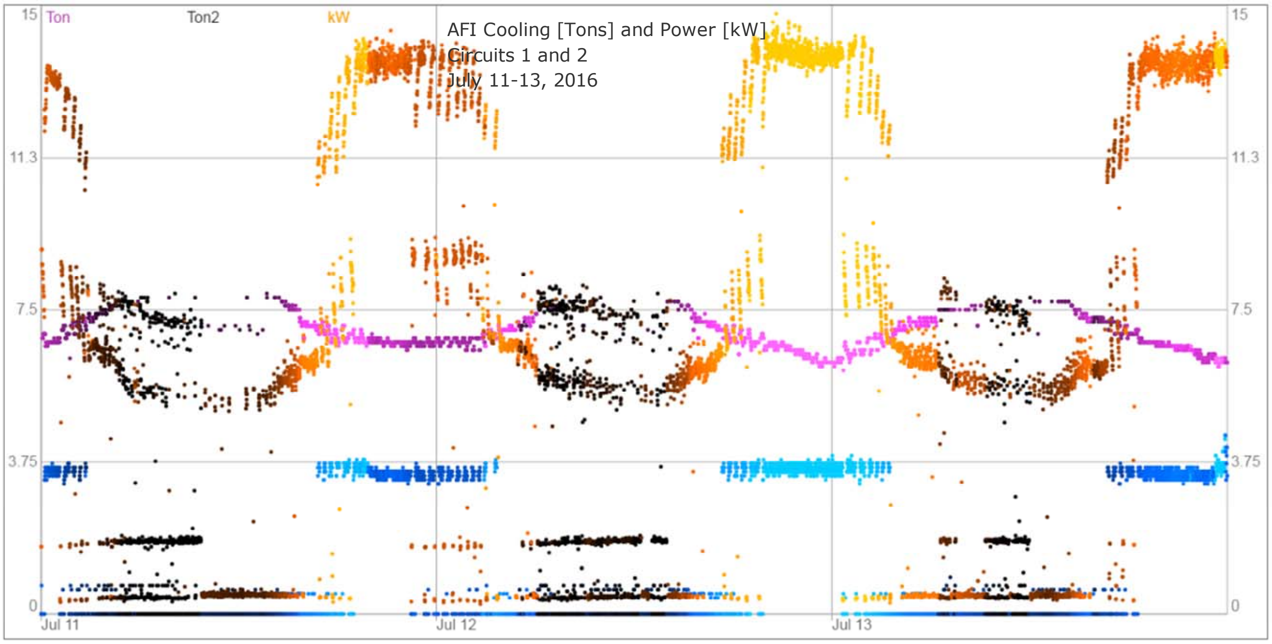


Figure 39. Fort Irwin Total Cooling Delivered by Each Circuit and Power Demand versus Time.

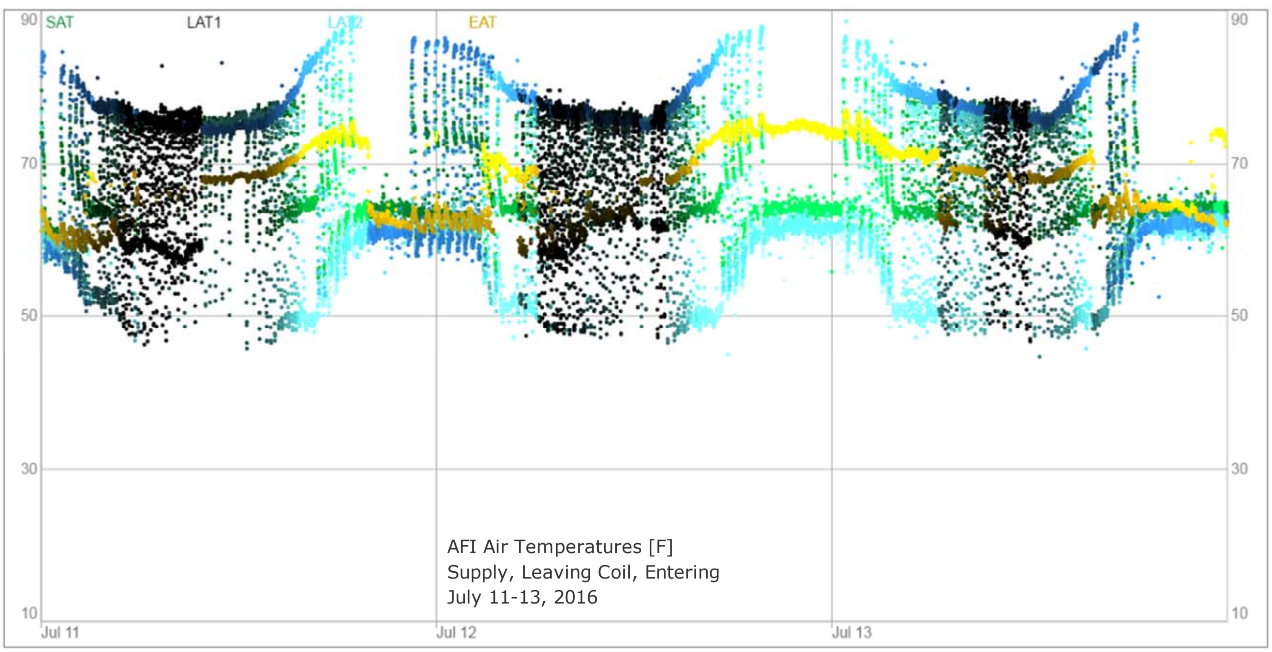


Figure 40. Fort Irwin Air Temperatures – Supply, Leaving Coil, and Entering Air versus Time.

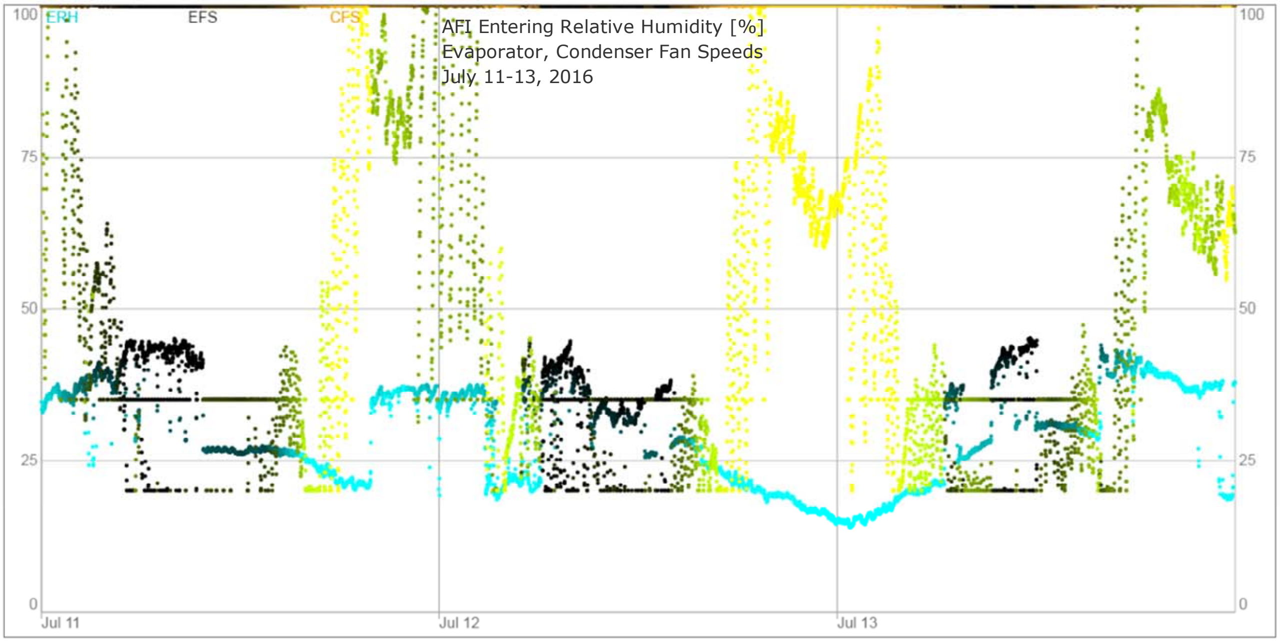


Figure 41. Fort Irwin Relative Humidity of Air Entering Air Conditioner Cooling Coil Long with Evaporator and Condenser Fan Speeds versus Time.

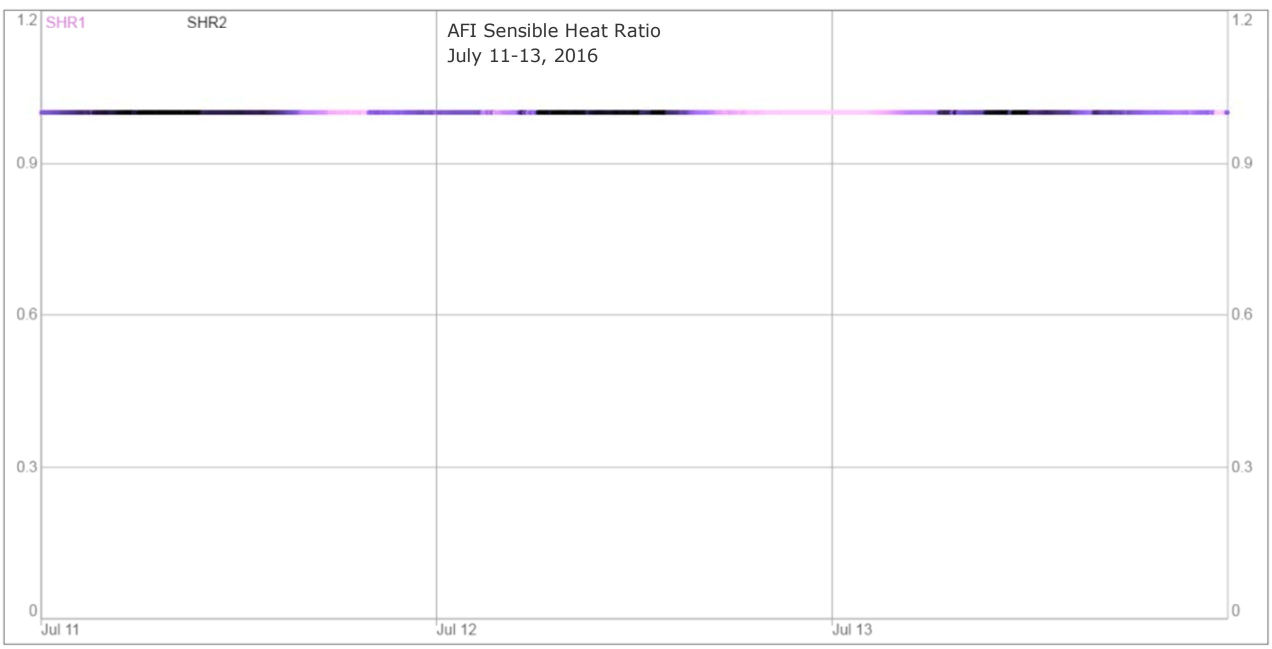
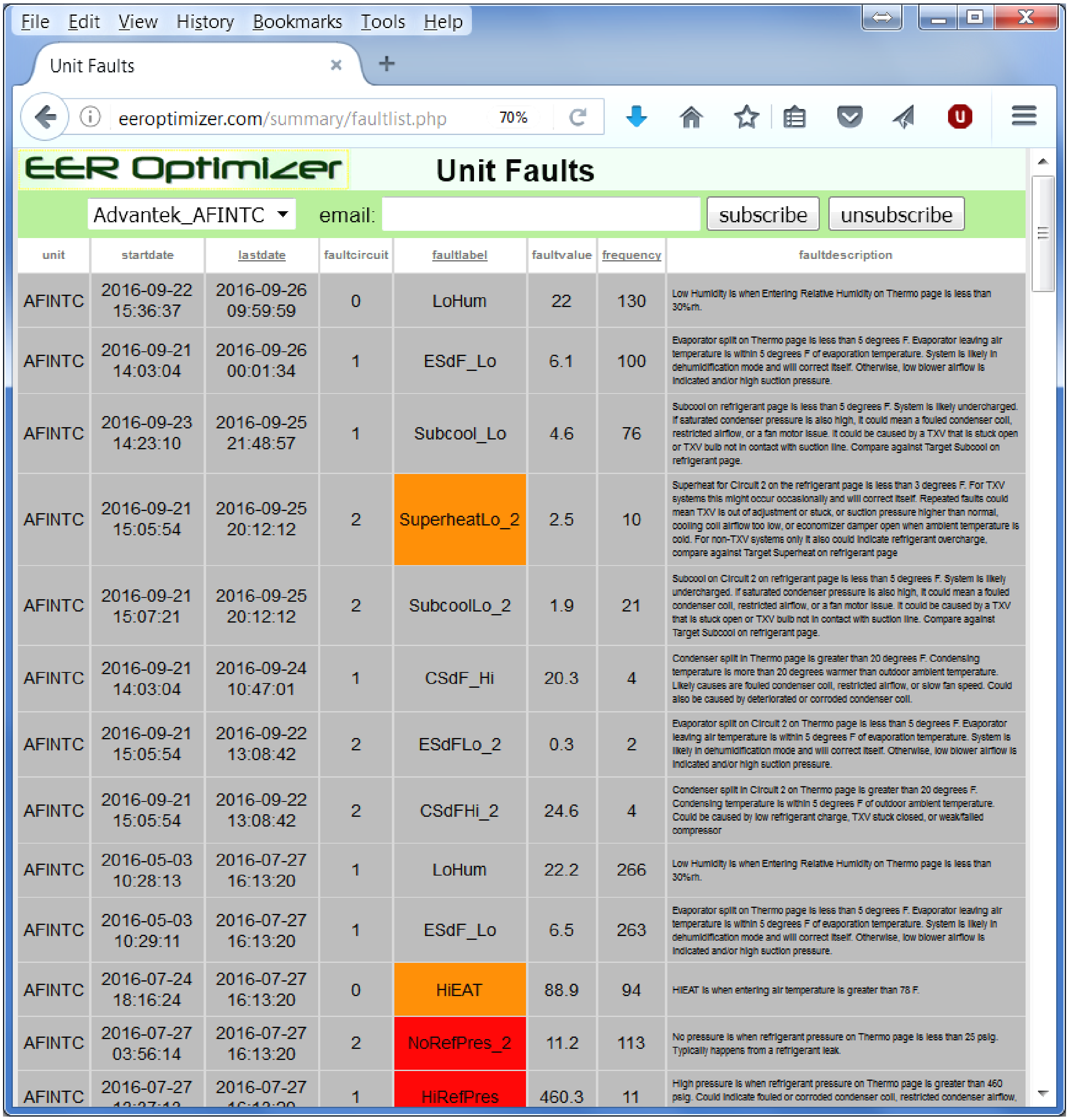


Figure 42. Fort Irwin Sensible Heat Ratio versus Time.



unit	startdate	lastdate	faultcircuit	faultlabel	faultvalue	frequency	faultdescription
AFINTC	2016-09-22 15:36:37	2016-09-26 09:59:59	0	LoHum	22	130	Low Humidity is when Entering Relative Humidity on Thermo page is less than 30%rh.
AFINTC	2016-09-21 14:03:04	2016-09-26 00:01:34	1	ESdF_Lo	6.1	100	Evaporator split on Thermo page is less than 5 degrees F. Evaporator leaving air temperature is within 5 degrees F of evaporation temperature. System is likely in dehumidification mode and will correct itself. Otherwise, low blower airflow is indicated and/or high suction pressure.
AFINTC	2016-09-23 14:23:10	2016-09-25 21:48:57	1	Subcool_Lo	4.6	76	Subcool on refrigerant page is less than 5 degrees F. System is likely undercharged. If saturated condenser pressure is also high, it could mean a fouled condenser coil, restricted airflow, or a fan motor issue. It could be caused by a TXV that is stuck open or TXV bulb not in contact with suction line. Compare against Target Subcool on refrigerant page.
AFINTC	2016-09-21 15:05:54	2016-09-25 20:12:12	2	SuperheatLo_2	2.5	10	Superheat for Circuit 2 on the refrigerant page is less than 3 degrees F. For TXV systems this might occur occasionally and will correct itself. Repeated faults could mean TXV is out of adjustment or stuck, or suction pressure higher than normal, cooling coil airflow too low, or economizer damper open when ambient temperature is cold. For non-TXV systems only it also could indicate refrigerant overcharge, compare against Target Superheat on refrigerant page
AFINTC	2016-09-21 15:07:21	2016-09-25 20:12:12	2	SubcoolLo_2	1.9	21	Subcool on Circuit 2 on refrigerant page is less than 5 degrees F. System is likely undercharged. If saturated condenser pressure is also high, it could mean a fouled condenser coil, restricted airflow, or a fan motor issue. It could be caused by a TXV that is stuck open or TXV bulb not in contact with suction line. Compare against Target Subcool on refrigerant page.
AFINTC	2016-09-21 14:03:04	2016-09-24 10:47:01	1	CSdF_Hi	20.3	4	Condenser split in Thermo page is greater than 20 degrees F. Condensing temperature is more than 20 degrees warmer than outdoor ambient temperature. Likely causes are fouled condenser coil, restricted airflow, or slow fan speed. Could also be caused by deteriorated or corroded condenser coil.
AFINTC	2016-09-21 15:05:54	2016-09-22 13:08:42	2	ESdFLo_2	0.3	2	Evaporator split on Circuit 2 on Thermo page is less than 5 degrees F. Evaporator leaving air temperature is within 5 degrees F of evaporation temperature. System is likely in dehumidification mode and will correct itself. Otherwise, low blower airflow is indicated and/or high suction pressure.
AFINTC	2016-09-21 15:05:54	2016-09-22 13:08:42	2	CSdFHi_2	24.6	4	Condenser split in Circuit 2 on Thermo page is greater than 20 degrees F. Condensing temperature is within 5 degrees F of outdoor ambient temperature. Could be caused by low refrigerant charge, TXV stuck closed, or weak/failed compressor
AFINTC	2016-05-03 10:28:13	2016-07-27 16:13:20	1	LoHum	22.2	266	Low Humidity is when Entering Relative Humidity on Thermo page is less than 30%rh.
AFINTC	2016-05-03 10:29:11	2016-07-27 16:13:20	1	ESdF_Lo	6.5	263	Evaporator split on Thermo page is less than 5 degrees F. Evaporator leaving air temperature is within 5 degrees F of evaporation temperature. System is likely in dehumidification mode and will correct itself. Otherwise, low blower airflow is indicated and/or high suction pressure.
AFINTC	2016-07-24 18:16:24	2016-07-27 16:13:20	0	HiEAT	88.9	94	HiEAT is when entering air temperature is greater than 78 F.
AFINTC	2016-07-27 03:56:14	2016-07-27 16:13:20	2	NoRefPres_2	11.2	113	No pressure is when refrigerant pressure on Thermo page is less than 25 psig. Typically happens from a refrigerant leak.
AFINTC	2016-07-27	2016-07-27	1	HiRefPres	460.3	11	High pressure is when refrigerant pressure on Thermo page is greater than 460 psig. Could indicate fouled or corroded condenser coil, restricted condenser airflow,

Figure 43. Fort Irwin Fault Detection & Diagnostics Screen Shows a Fault ESdF Low Occurred 100 Time between September 21 to 26, 2016.

The current faults value of 6 degrees-F is close to the trip value so this could be caused by the controlled blower speed being set at its low limit to minimize energy usage.

5.6.3 Regression Data Samples

Shown here are samples of data analyzed data spanning a few weeks during the test period to graphically illustrate the results that were obtained. There are 3 regression plots per chart for three operating modes, for each of 3 demonstration sites, for a total of 9 charts. The data point color shading is keyed to the calendar date according to the scale at the top left of each chart. The resulting IEER values derived from the regression analysis are shown in the 3 bar charts following the regression plots. The EER Optimizer run mode selection capability was utilized for energy efficiency comparisons, the user can select one of three operating modes as follows:

MANUAL

Reverts to factory controls, the blower speed is 100%, the condenser fan speed is 100%, the refrigerant charge is at factory specification. The occupied temperature set point is met, while dehumidification is passively provided and occupied space humidity floats.

AUTOMATIC

The occupied space temperature and humidity set points are simultaneously met via blower speed and damper position adjustments while maximum energy efficiency is sought by minimizing electric power demand. Condenser fan speed is 100% and refrigerant charge is at factory specification.

OPTIMIZE

Maximum energy efficiency is sought via continuous adjustment of all operational parameters to minimize the power consumption per unit of cooling delivered, while at the same time meeting the occupied space temperature and humidity set points. Optimize mode maximizes EER; the Energy Efficiency Ratio is the cooling delivered in units of Btuh (Btu per hour) divided by the power demand in units of Watts. By maximizing the EER at all operating conditions, the Integrated EER (IEER) is in turn maximized as well.

The standard efficiency metric for HVAC equipment is the Integrated Energy Efficiency Ratio, IEER. Data analysis followed *ANSI/AHRI Standard 340/360-2007 with Addenda 1 and 2,* which is the standard for performance testing of unitary DX equipment used by all manufacturers. IEER is a weighted average of four adjusted EERs at 95.0F, 81.5F, 68.0F, and 65.0F ambient temperature, with the Standard’s intention that IEER is a better predictor of actual installed energy use over a typical cooling season than EER alone.

EER at each of the four standard ambient temperatures was calculated using linear regression coefficients for cooling [Tons] and power demand [kW] against ambient temperature, shown as black lines in each of the following charts. The data points are clustered in cloud around each line as expected; the amount of cooling, the power demand and the efficiency are functions of / affected by numerous other variables in addition to ambient temperature and these relationships are inherently non-linear. A linear regression against ambient temperature was chosen to match the methodology defined by *ANSI/AHRI Standard 340/360-2007.* A multivariate non-linear regression analysis would present data points neatly following a regression surface; however, such an analysis would not be useful in this context.

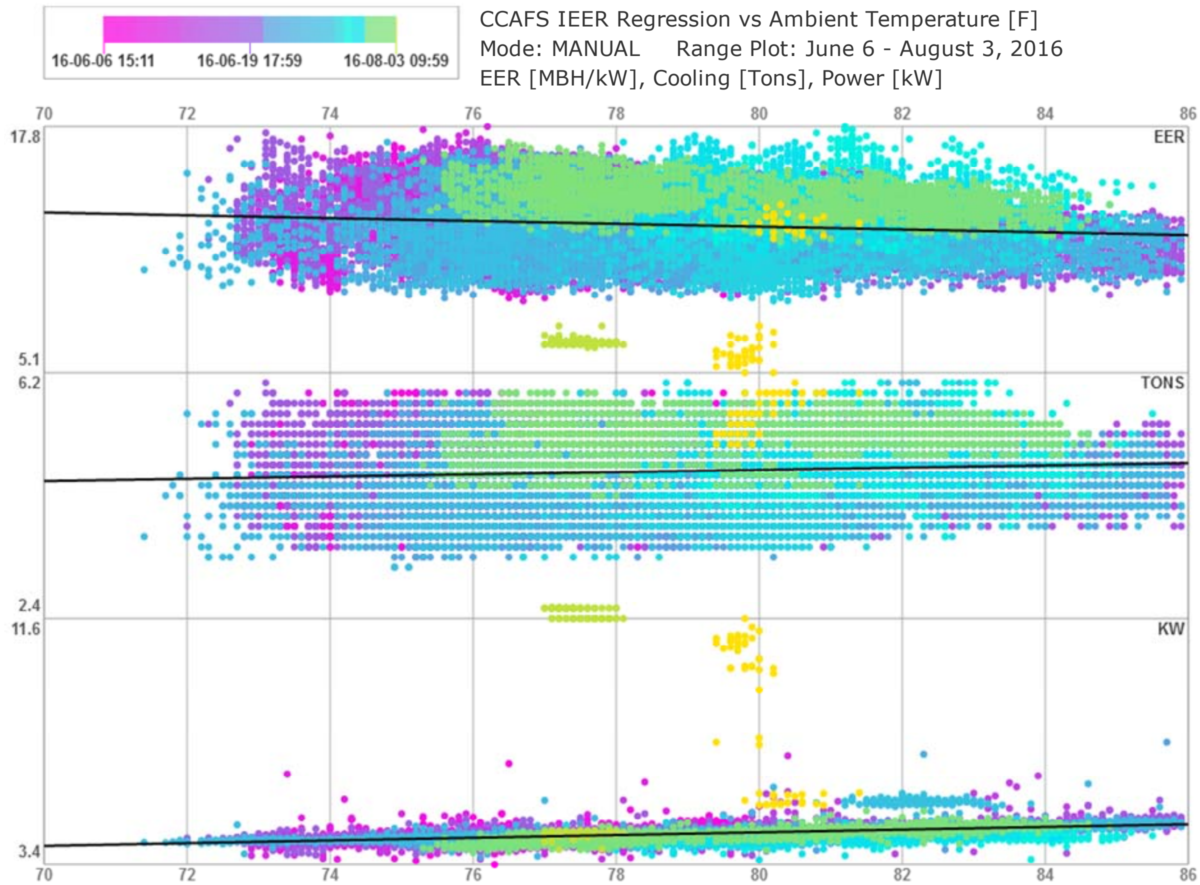


Figure 44. CCAFS IEER Regression versus Ambient Temperature [F] in Manual Mode.

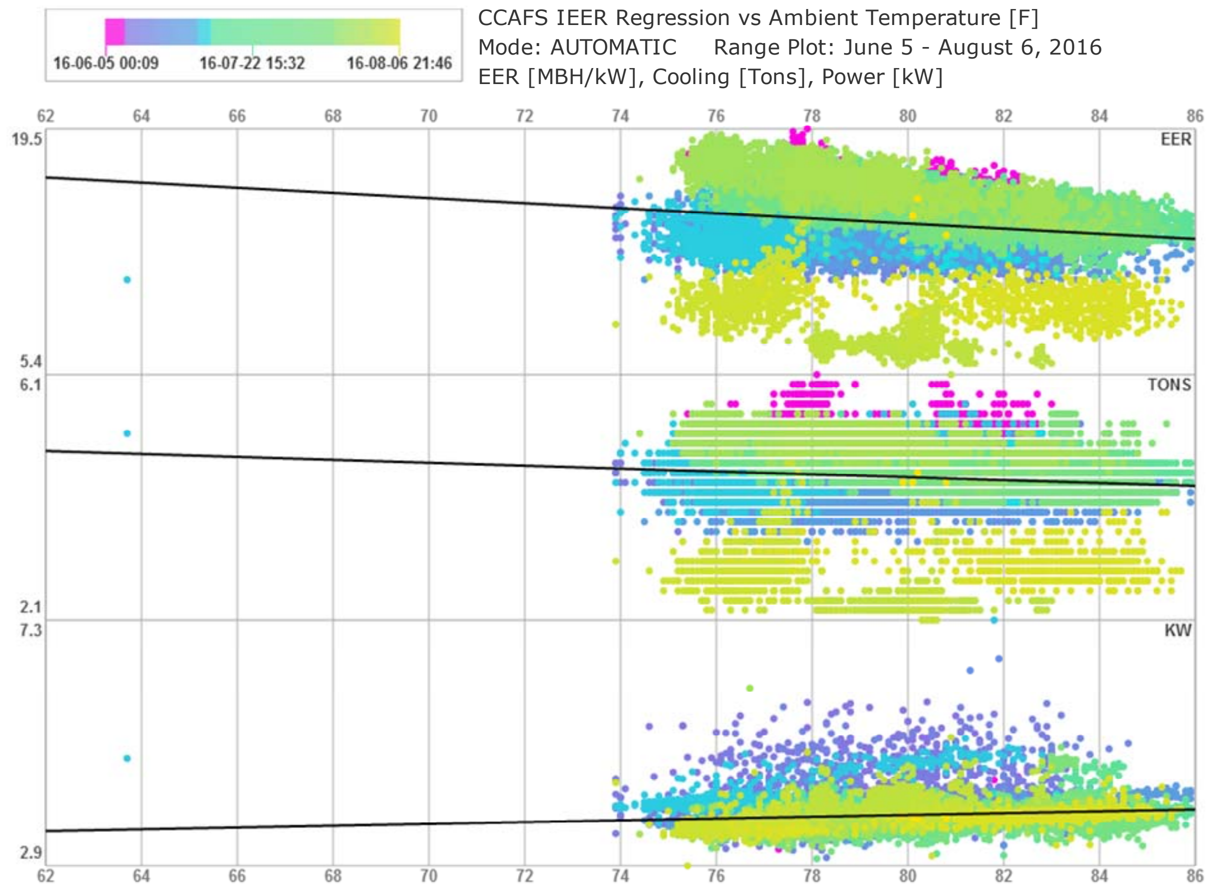


Figure 45. CCAFS IEER Regression versus Ambient Temperature [F] in Automatic Mode.

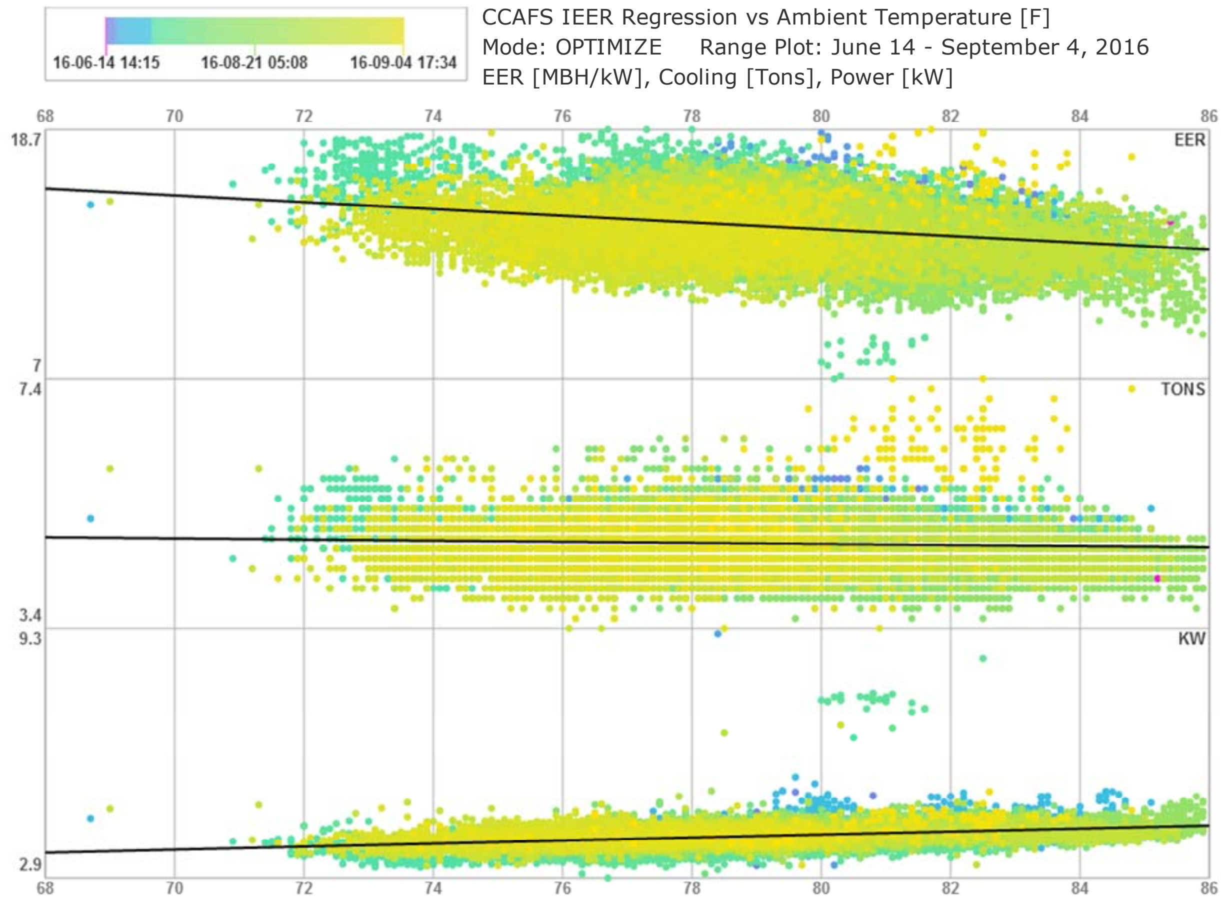


Figure 46. CCAFS IEER Regression versus Ambient Temperature [F] in Optimize Mode.

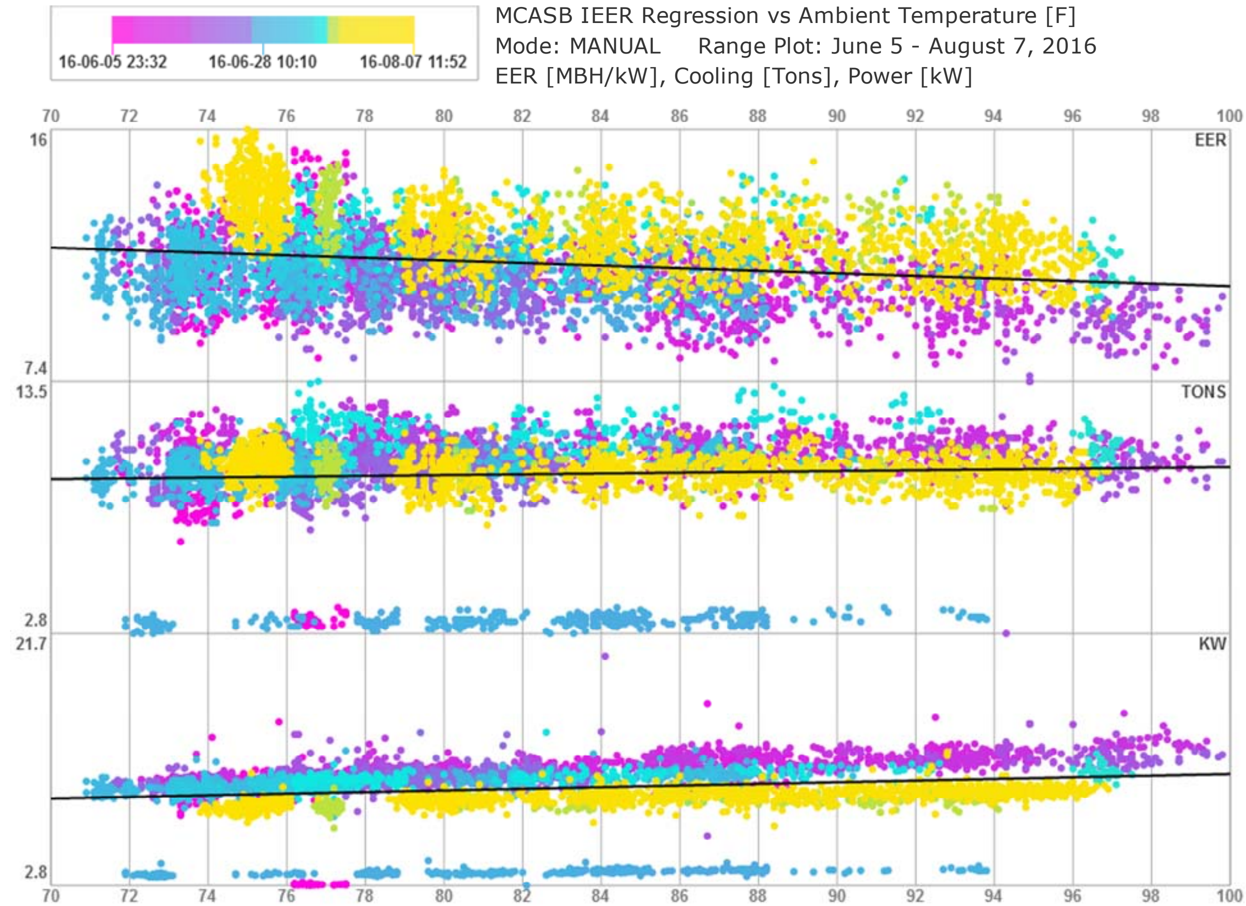


Figure 47. MCASB IEER Regression versus Ambient Temperature [F] in Manual Mode.

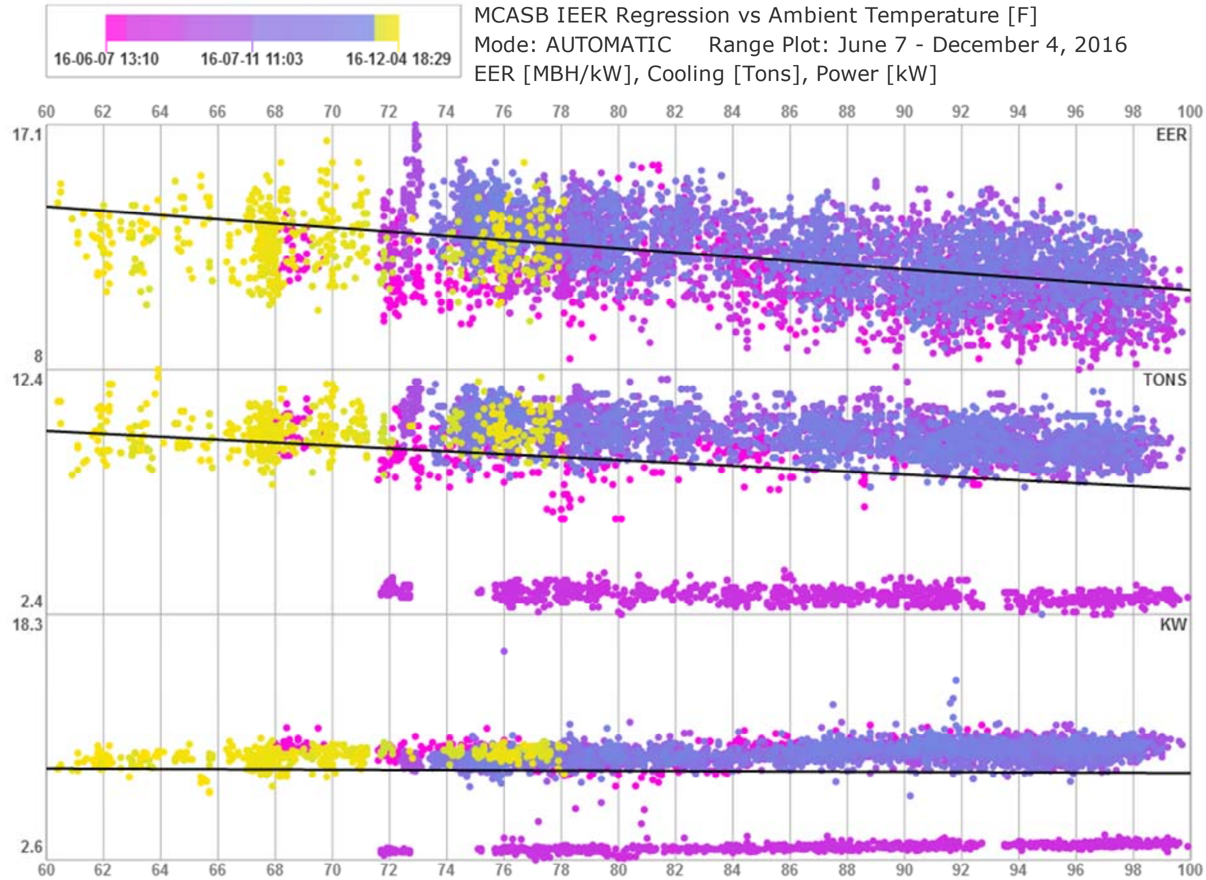


Figure 48. MCASB IEER Regression versus Ambient Temperature [F] in Automatic Mode.

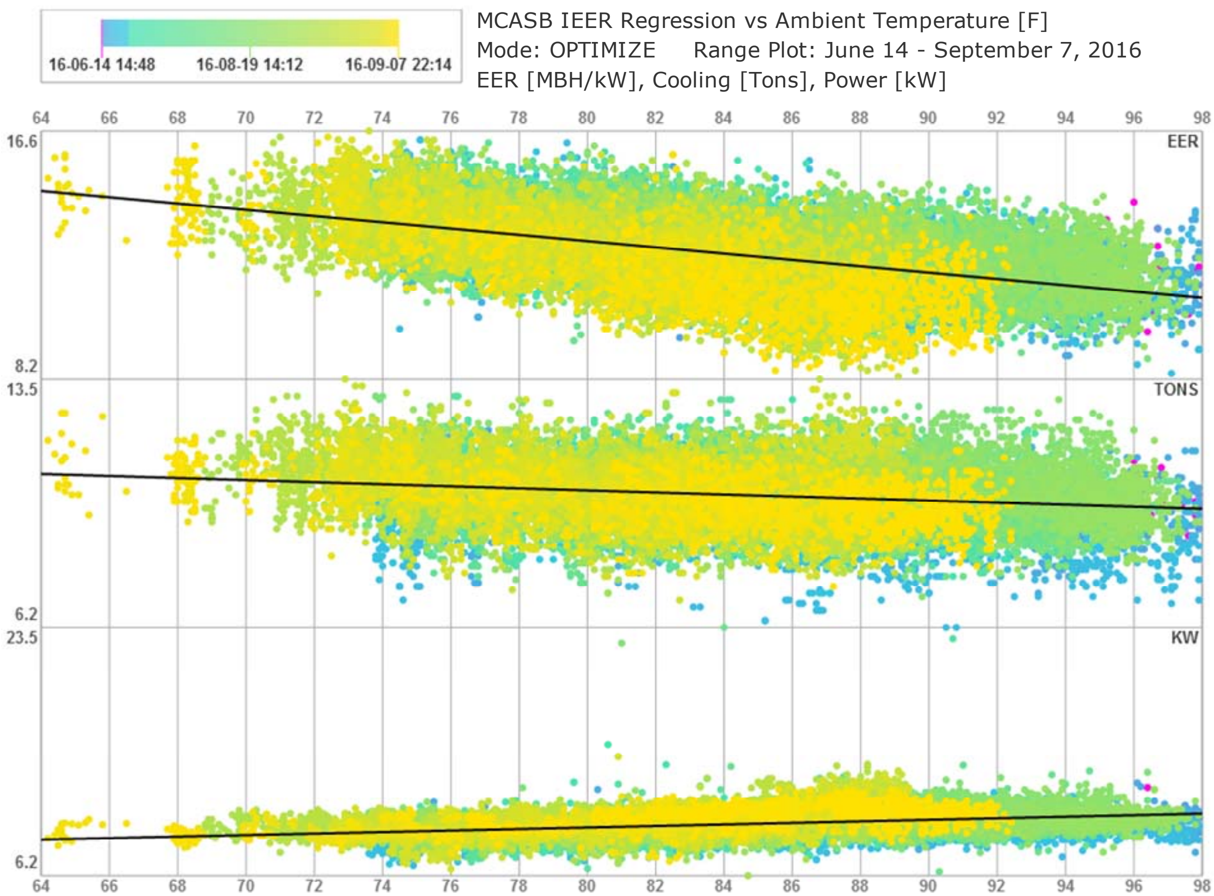


Figure 49. MCASB IEER Regression versus Ambient Temperature [F] in Optimize Mode.

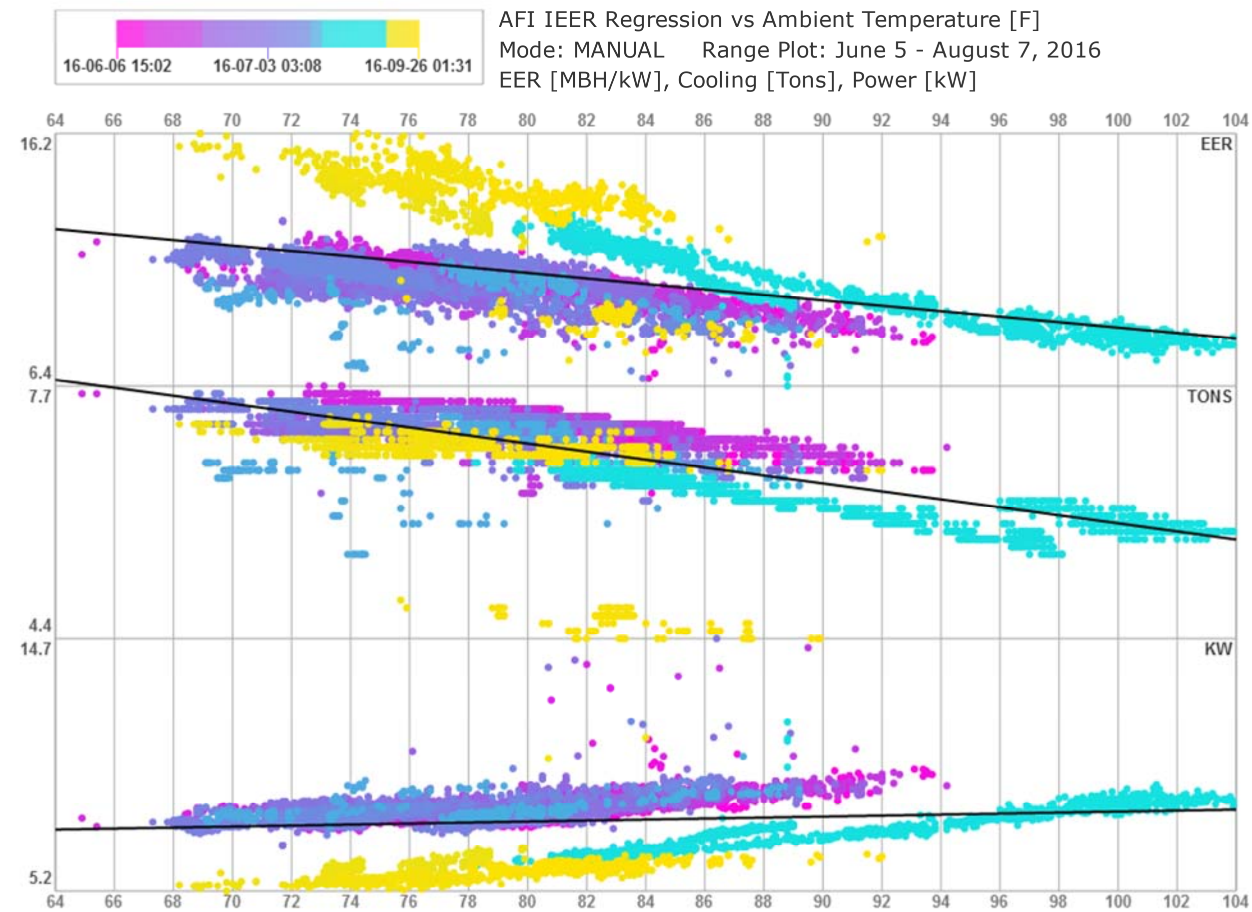


Figure 50. AFI IEER Regression versus Ambient Temperature [F] in Manual Mode.

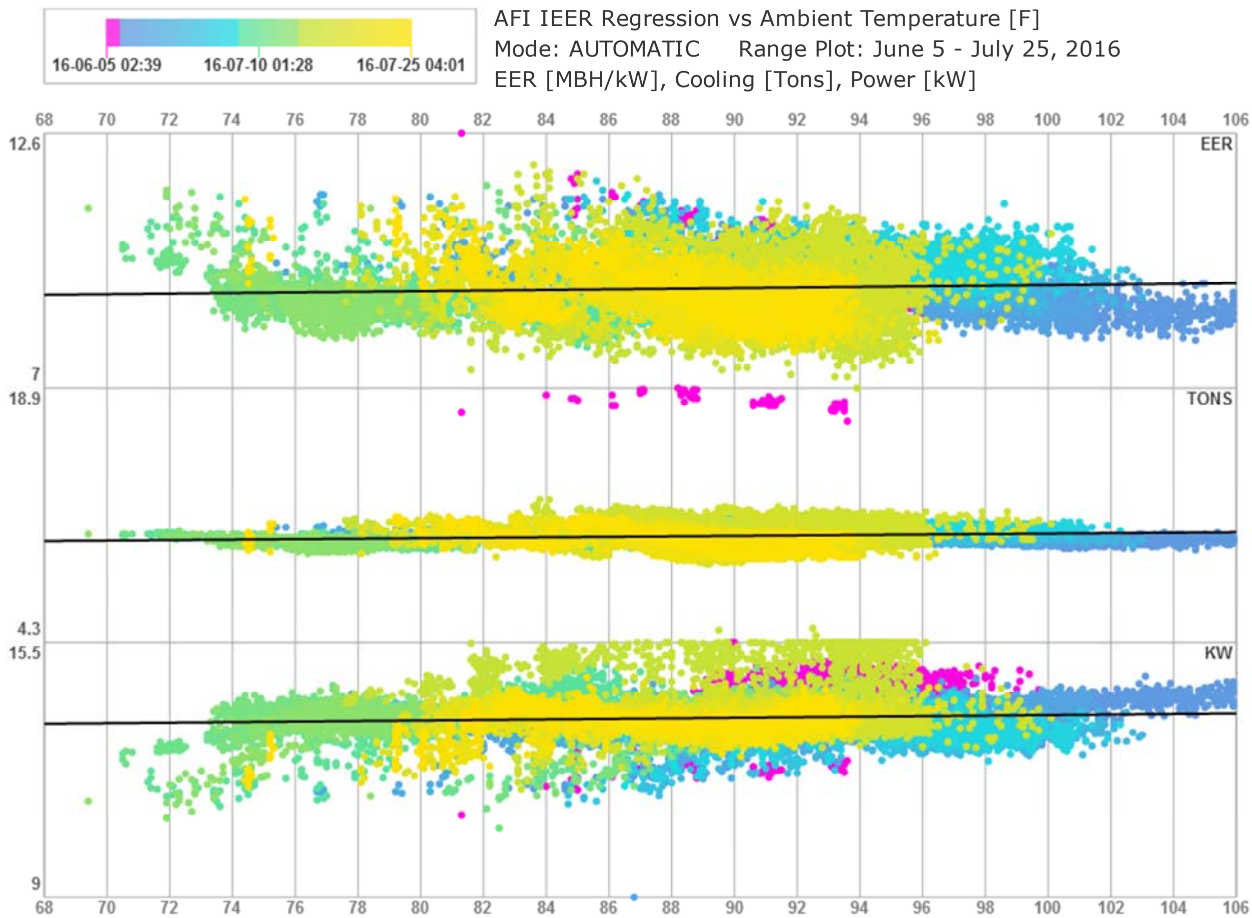


Figure 51. AFI IEER Regression versus Ambient Temperature [F] in Automatic Mode.

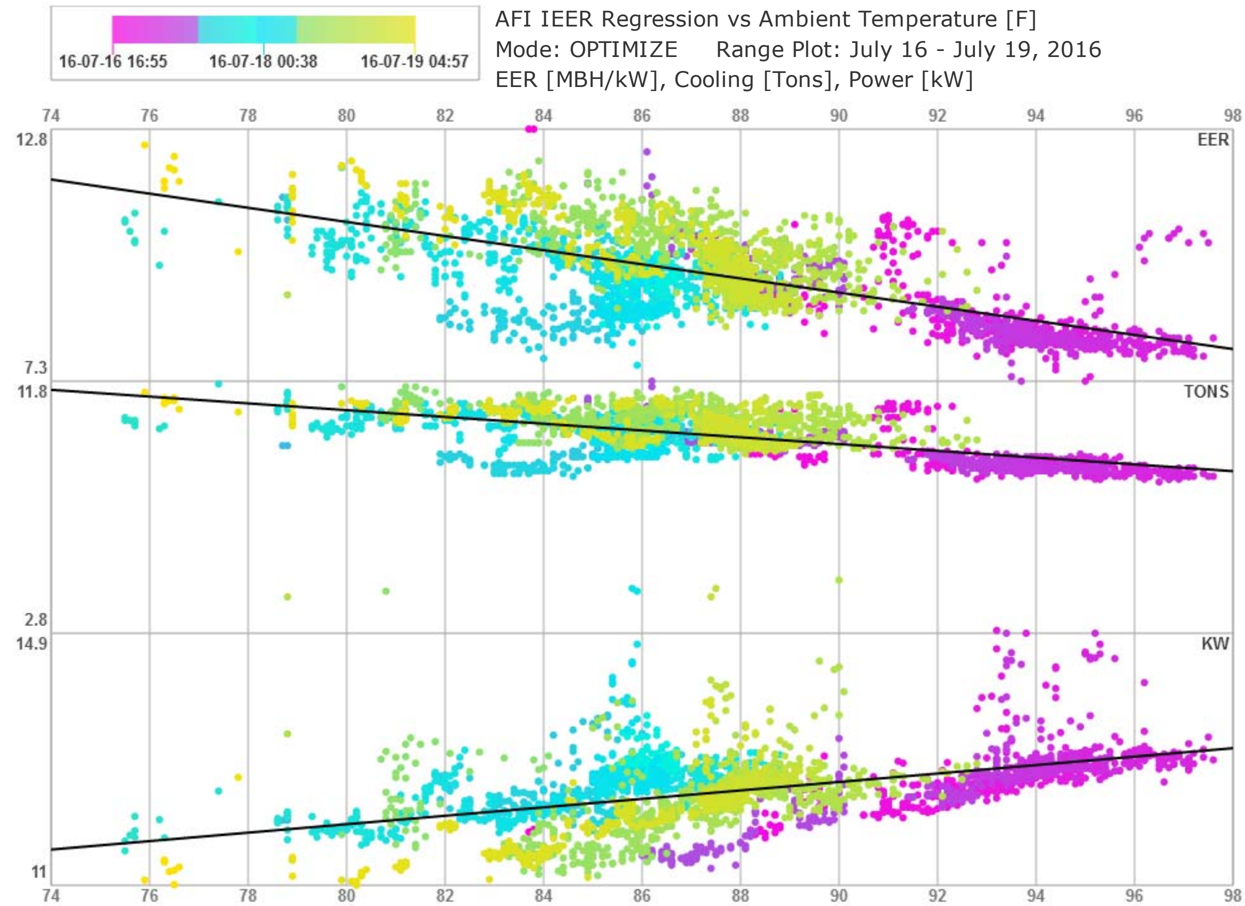


Figure 52. AFI IEER Regression versus Ambient Temperature [F] in Optimize Mode.

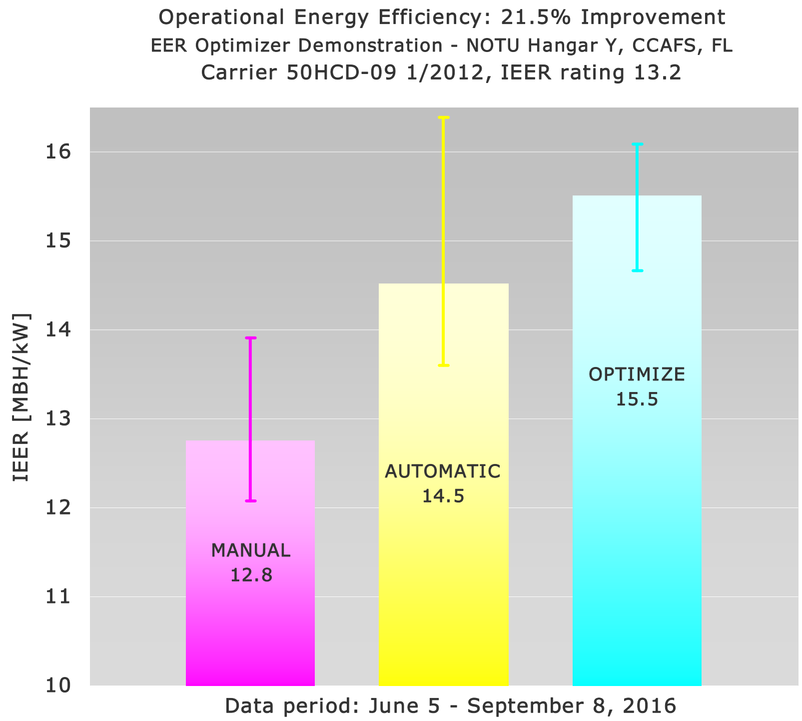


Figure 53. CCAFS Measured IEER Operating in Manual, Automatic, and Optimize Modes.

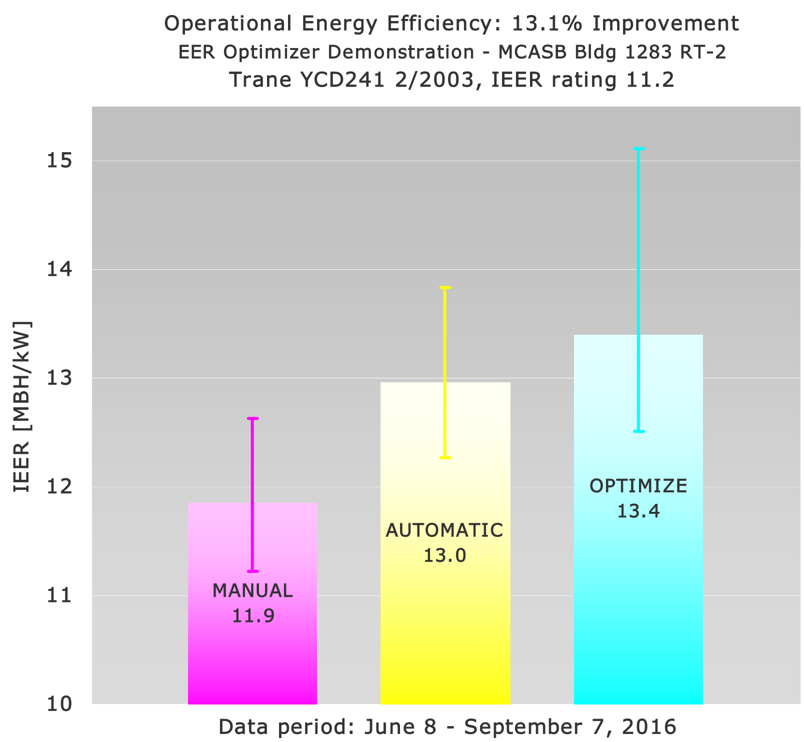


Figure 54. MCASB measured IEER Operating in Manual, Automatic, and Optimize Modes.

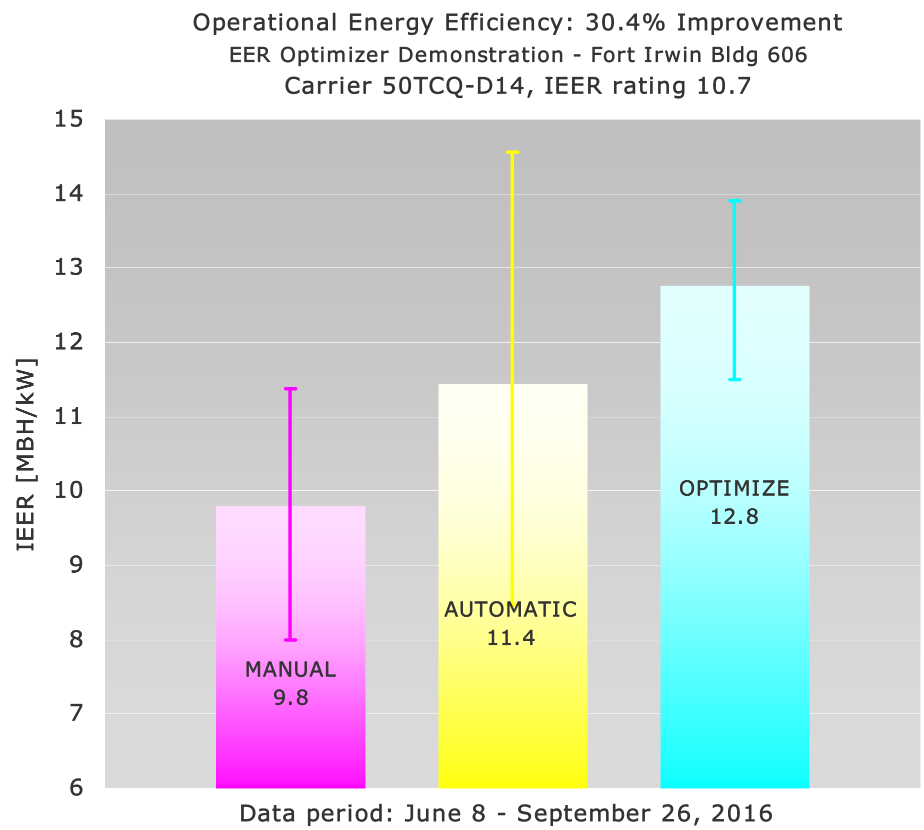


Figure 55. MCASB Measured IEER Operating in Manual, Automatic, and Optimize Modes.

5.6.4 Occupied Space Comfort Condition Samples

Shown here are occupied space temperature and humidity data spanning approximately one month during the baseline and test periods to graphically illustrate the results that were obtained. There are 6 charts, one "before" and one "after" for each of the three demonstration sites. The ASHRAE Standard 55 comfort envelope is outlined on the charts for reference.

<u>CCAFS</u>

Controls at CCAFS had constant held temperature and humidity set points. Baseline temperature set point was 74F and test period temperature setpoint was 73F; temperature was lowered in response to occupant comments. Humidity setpoint range was 45 - 55%$_{rh}$.

<u>MCASB</u>

Controls at MCASB were programmed for an unoccupied mode with space temperature set to 80F and active dehumidification was suspended. Baseline temperature set point was 73F; setpoint was increased to 75F during the test period according to energy management policy. Humidity setpoint range was 50 - 60%$_{rh}$.

Fort Irwin (AFI)

Temperature set point was 75F, 24 hours per day, every day of the week. Humidity setpoint range was 40 - 50%rh. The extremely hot dry outdoor conditions strongly influenced space temperature and humidity in this metal-roofed, minimally insulated, open frame building.

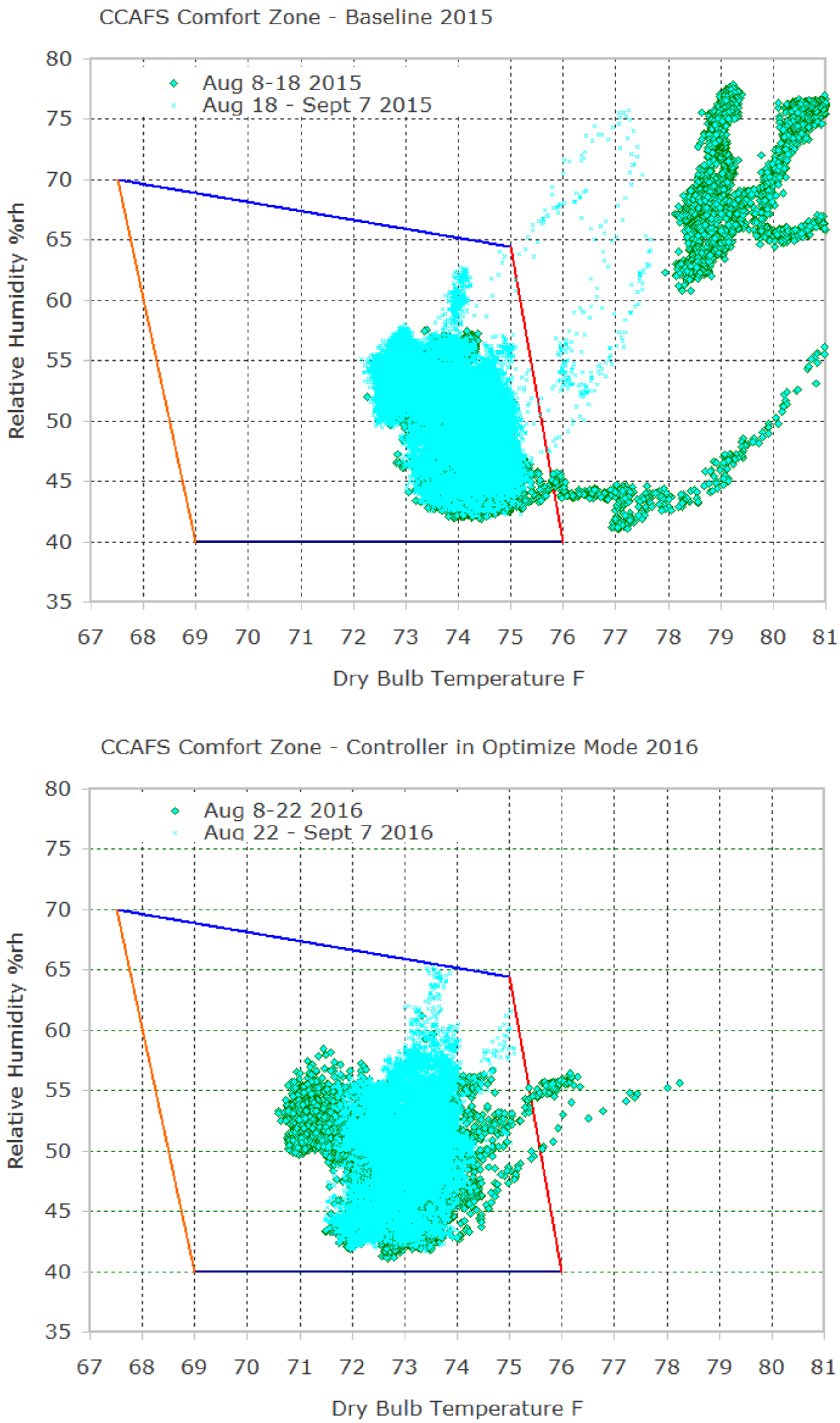


Figure 56. CCAFS Comfort Zone Plots of Occupied Space Temperature versus Relative Humidity for Baseline 2015 (top) and Test 2016 (bottom).

In baseline plot, cluster of points to right is failed #2 contactor.

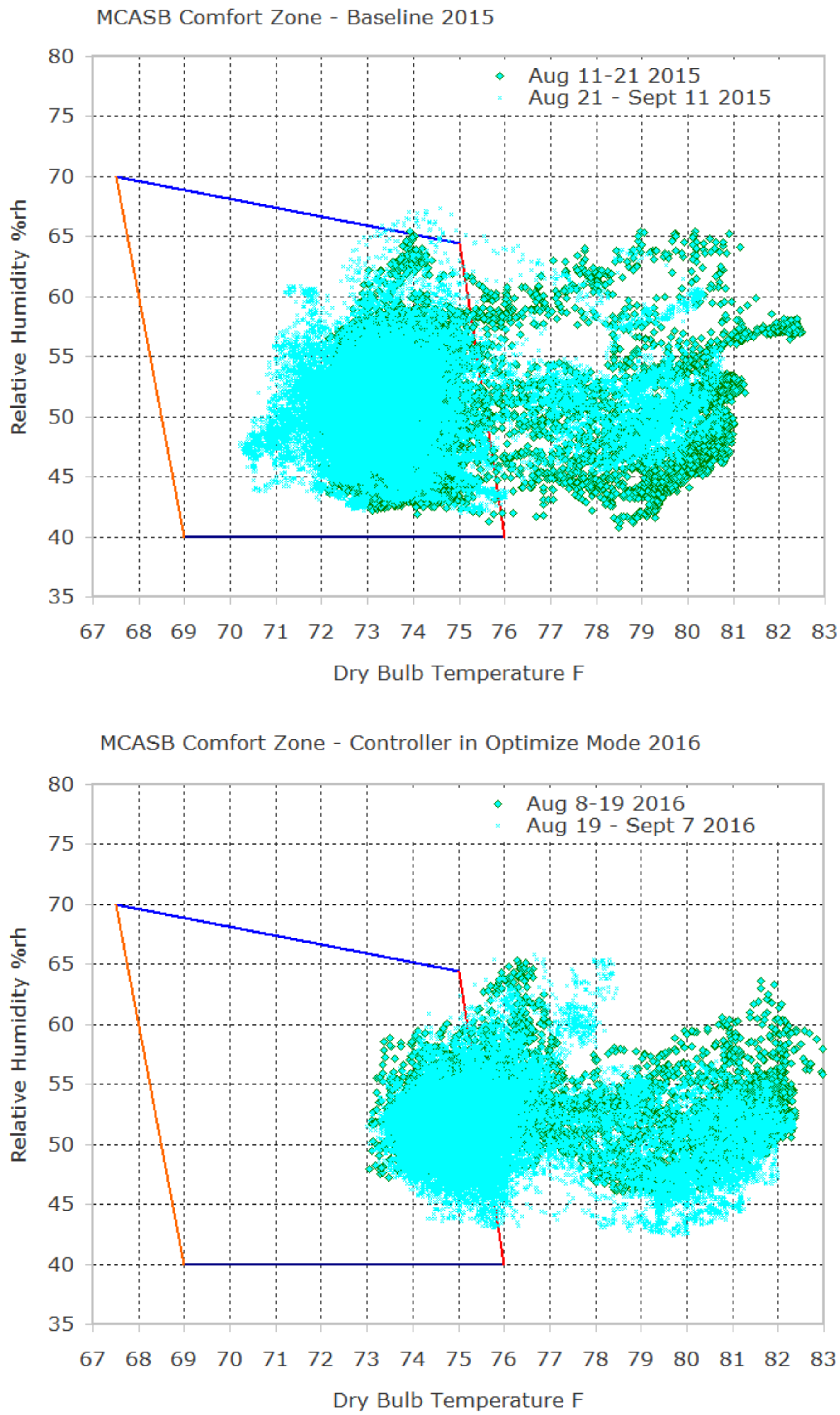


Figure 57. MCASB Comfort Zone Plots of Occupied Space Temperature versus Relative Humidity for Baseline 2015 (top) and Test 2016 (bottom).

Cluster of points to the right is unoccupied mode.

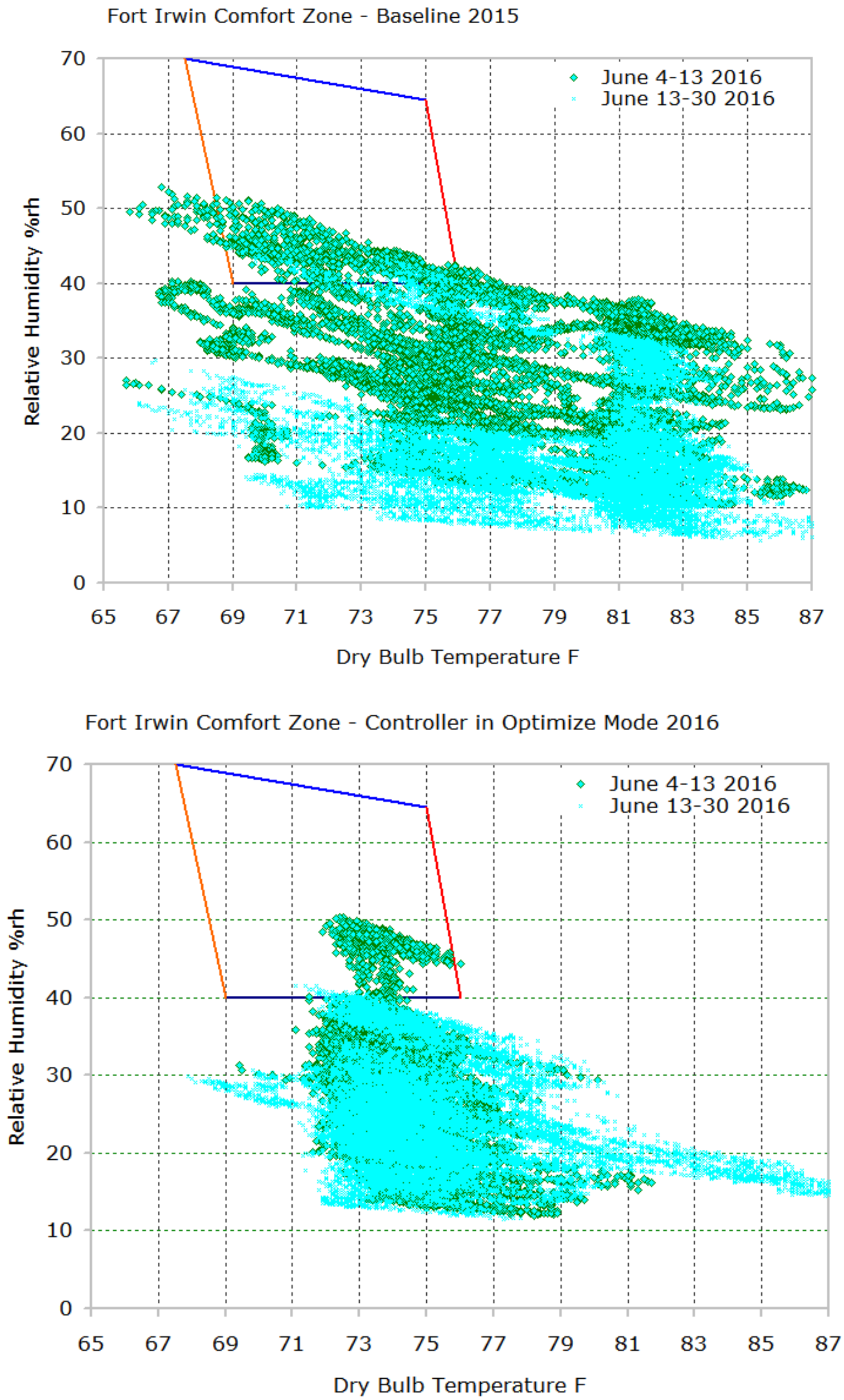


Figure 58. AFI Comfort Zone Plots of Occupied Space Temperature versus Relative Humidity for Baseline 2015 (top) and Test 2016 (bottom).

Ambient humidity at Fort Irwin is very dry and no humidification is provided.

5.6.5 Handheld Portable Performance Measurements

A total of 30 DX HVAC units were randomly selected at Cape Canaveral Air Force Station (CCAFS), Marine Corps Air Station Beaufort (MCASB), and Fort Irwin National Training Center (AFI). The i-Optimize portable system was used to test energy efficiency (EER and IEER), cooling capacity (Tons) and detect issues such as low refrigerant, stuck TXV, restricted airflow, fouled condenser coil, compressor wear and the like. EER and IEER indicate the amount of cooling provided per unit of electrical energy consumed in units of Btuh per Watt.

<u>CCAFS FL</u>

The average age of the ten tested units was 10.9 years. The as-found energy efficiency degradation versus factory rating averaged 39%. The average factory energy efficiency rating of the units is IEER 11.9, the measured energy efficiencies average IEER 7.2, and the energy efficiency after servicing is IEER 9.3, which is a 22% improvement. The refrigerant circuits averaged 18% undercharged, ranging up to 6.4 lbs undercharged. Correcting refrigerant charge accounted for about 10% improvement in energy efficiency.

Diagnostics included fouled condenser coils on all units except building 1115 and 52003, likely due to the corrosive coastal salt air. Otherwise, the units appeared to be in relatively good working order for their advanced age. With servicing the loss of energy efficiency from factory rating was reduced from 39% to 14%.

<u>MCASB SC</u>

The average age of the units was 13.3 years. The as-found energy efficiency degradation versus factory rating averaged a 42% loss of efficiency. The average factory energy efficiency rating of the units is IEER 11.0, the measured energy efficiencies average IEER 6.4, and the energy efficiency after servicing was IEER 8.8, which is a 26% improvement. The refrigerant circuits averaged 18% undercharged, ranging from 3.8 lbs overcharged to 7.1 lbs undercharged. Correcting refrigerant charge accounted for about 10% improvement in energy efficiency.

Diagnostics included a control issue on RT-5, fouled condenser coils on RT-6 and RT-9, and a failed condenser fan on RT-7. Given the advanced age of the units, they appeared to be in functional working order. However, even with servicing there is a 20% loss of energy efficiency from factory rating.

<u>FORT IRWIN CA</u>

The average age of the units was 7.8 years. The as-found energy efficiency degradation versus factory rating averaged 25%. The average factory energy efficiency rating of the units is IEER 11.3, the measured energy efficiencies average IEER 8.4, and the energy efficiency after servicing is IEER 10.3, which was a 19% improvement. The refrigerant circuits averaged 16% undercharged, ranging from 0.1 to 9.4 lbs undercharged. Adding refrigerant accounted for about 10% improvement in energy efficiency.

Diagnostics included failed condenser fans on two units at building 308 and the food court unit at Exchange bldg 918. Otherwise, the units appeared to be in relatively good working order. With servicing on these newer units there is an 8% loss of energy efficiency from factory rating.

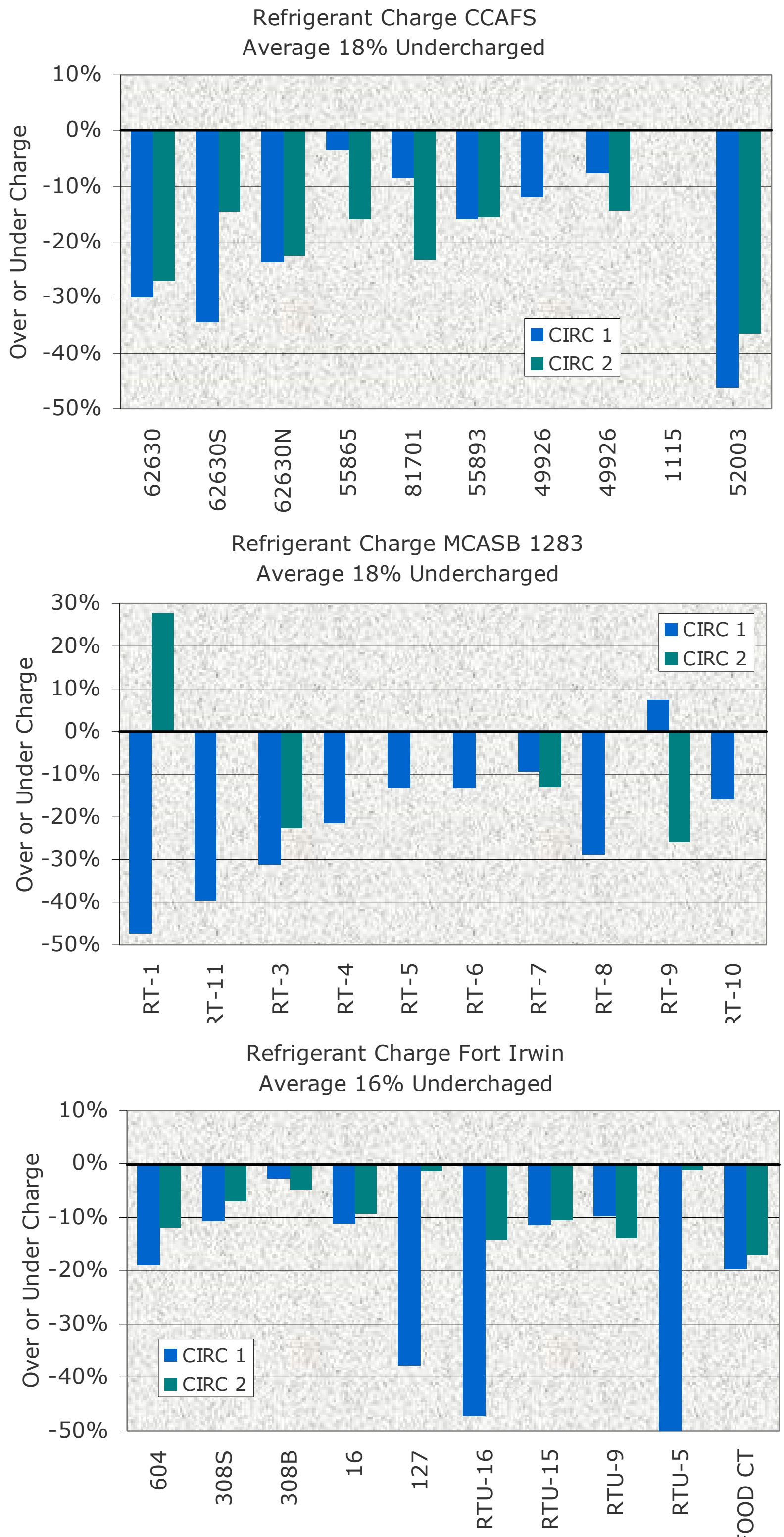


Figure 59. Refrigerant Charge Level Charts Showing Percent Over or Under Charge of Ten DX units at CCAFS, MCASB, and Fort Irwin.

All circuits but three were found to be undercharged.

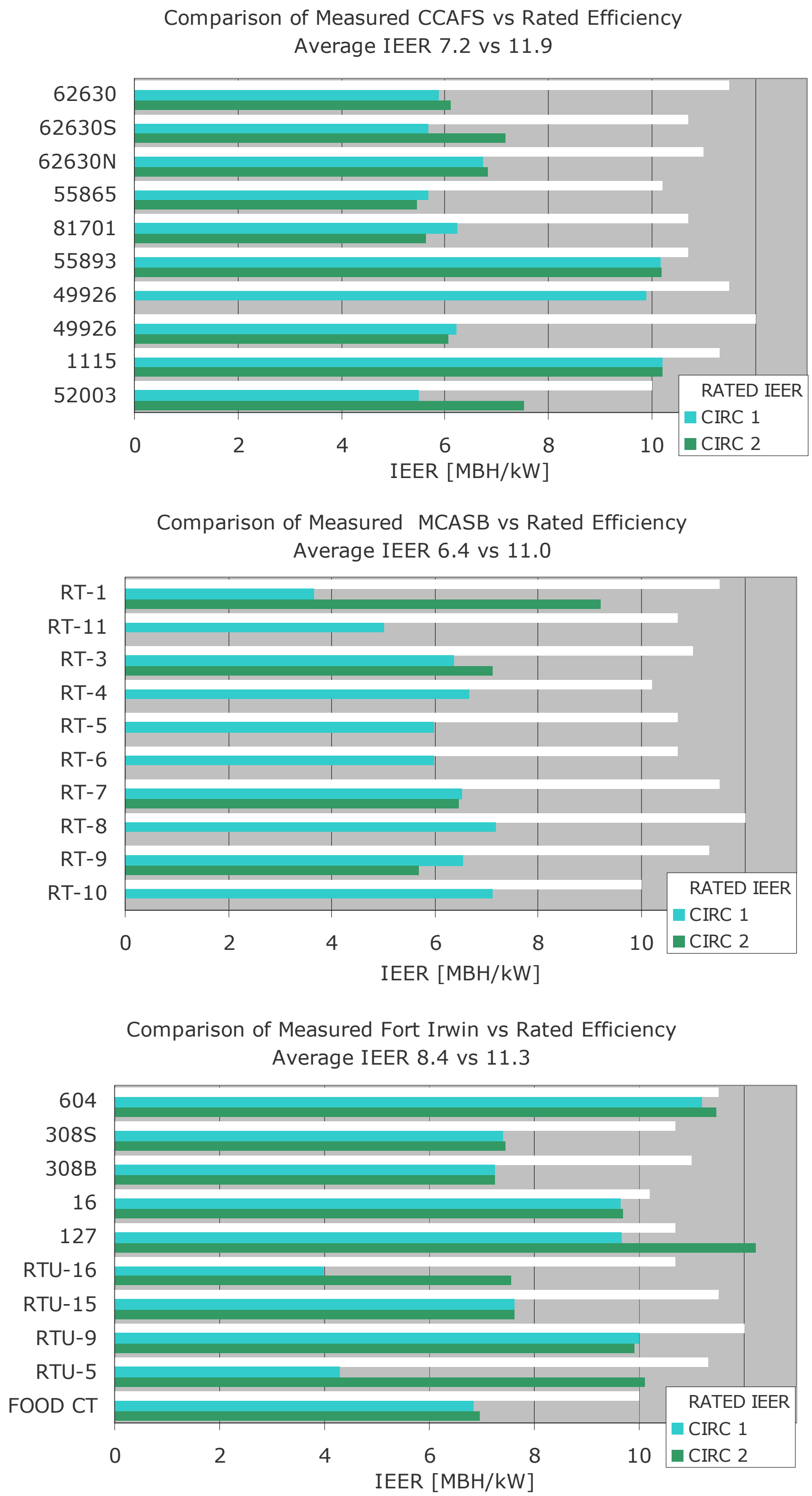


Figure 60. Energy Efficiency Charts Showing Factory Rating Compared with Field Measured Integrated Energy Efficiency Ratio (IEER) of Ten DX Units at CCAFS, MCASB, and Fort Irwin.

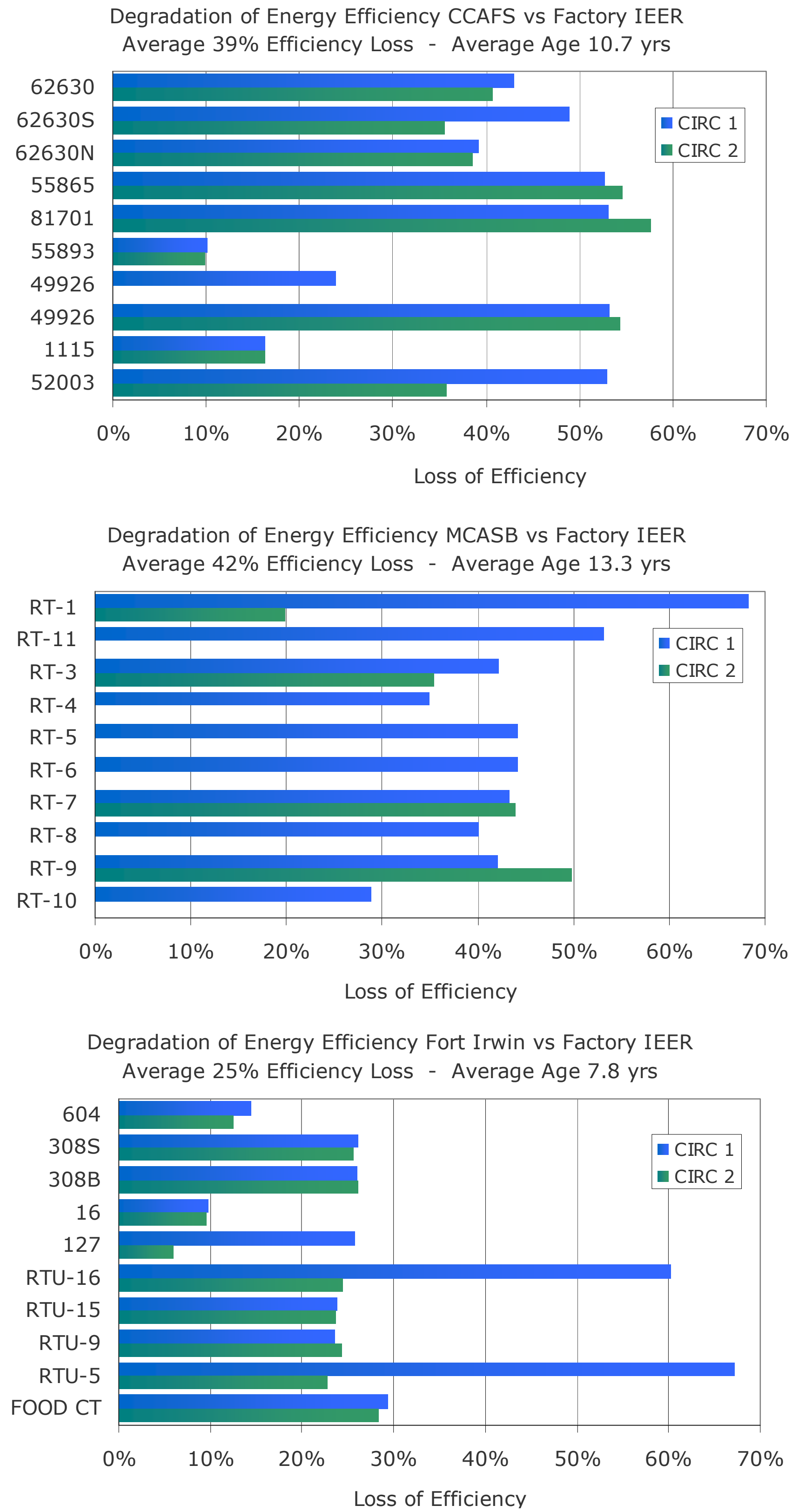


Figure 61. Charts Showing Energy Efficiency Degradation from Factory Rating of Ten DX Units at CCAFS, MCASB, and Fort Irwin.

6.0 PERFORMANCE ASSESSMENT

6.1 PERFORMANCE OBJECTIVES FOR ONBOARD TECHNOLOGY

6.1.1 Increase AC Units Energy Efficiency

Cooling season electric demand and consumption – both actual and adjusted to cooling degree-day (CDD) weather data for straightforward adaptation to other climate locations – is listed in the tables below. The reduction in normalized energy usage averaged 28% among the three demonstration sites. Reduction at Fort Irwin (AFI) was 30%, reduction at MCASB was 24%, and reduction at CCAFS was 30%. There was no significant change in peak electric demand between the baseline and test periods.

Field-measured IEER (Integrated Energy Efficiency Ratio – weighted Btuh/Watt) was calculated for each demonstration unit. All three units exhibited a significant increase in IEER and commensurate decrease in normalized energy use for a cooling season, relative to baseline IEER measurements. The average improvement in measured IEER was 19.7%. Improvement at Fort Irwin (AFI) was 34%, improvement at MCASB was 13%, and improvement at CCAFS was 12%. Propagation of error analysis shows IEER measurement accuracy of ±0.6 Btuh/Watt which is about 4% of the measured test values.

Table 3. Energy Efficiency and Energy Consumption Comparison of the Test Period with the Baseline Period Normalized for Number of Days and Weather Severity.

ENERGY EFFICIENCY - Baseline

Site	FLEOH per Day	Efficiency IEER Rated	Efficiency IEER Data	Operating Cost $/Day	Operating Cost $/CDD
MCASB (SC)	13.1	11.2	11.8	27.30	2.07
AFI-NTC (CA)	7.2	10.7	9.5	15.16	0.92
CCAFS (FL)	12.9	13.2	13.9	12.96	0.78

ENERGY EFFICIENCY - Test

Site	FLEOH per Day	Efficiency IEER Rated	Efficiency IEER Data	Operating Cost $/Day	Operating Cost $/CDD
MCASB (SC)	14.3	11.2	13.4	29.71	1.58
AFI-NTC (CA)	6.9	10.7	12.8	12.56	0.64
CCAFS (FL)	7.5	13.2	15.5	9.64	0.54

Table 4 below compares cooling capacity and raw electric energy usage data of baseline period data with test period data. Table 2 in section 5.4 shows the number of days and cooling-degree days in each test period. Weather was more severe at all three demonstration sites during the test period – cooling degree-days were 43%, 19% and 6% higher during the test period at MCASB, Fort Irwin and CCAFS respectively. AFI-NTC used 9,685 kWh during the test period and 3,466 kWh in the baseline period – the test period spanned 110 days and the baseline period spanned 32 days, accounting for the approximately three times energy usage. Cooling degree days per day is a metric for weather severity and was used to normalize comparisons between the baseline and test periods to arrive at the values in Table 3.

Table 4. Raw Baseline and Test Period Cooling-degree Days, Cooling Capacity [Tons] and Energy Demand [kW] and Energy Usage [kWh] ¶ not normalized for number of days or weather severity.

CAPACITY and ENERGY - Baseline

	CDD	Cooling Tons		Energy Used	
Site	per Day	Data	Rated	kW	kWh
MCASB (SC)	13.2	21.5	20.8	20.9	19,929
AFI-NTC (CA)	16.5	8.9	12.5	15.1	3,466
CCAFS (FL)	16.7	7.2	8.1	7.2	9,997

CAPACITY and ENERGY - Test

	CDD	Cooling Tons		Energy Used	
Site	per Day	Data	Rated	kW	kWh
MCASB (SC)	18.8	19.6	20.8	20.7	27,039
AFI-NTC (CA)	19.6	8.9	12.5	12.9	9,865
CCAFS (FL)	17.8	9.2	8.1	9.2	6,540

A comparison of field measured IEER versus a test period benchmark is shown in the table below. The benchmark values account for equipment deterioration that occurred in the 20 months from the 2014 baseline period to the 2016 test period, especially at CCAFS where the benchmark IEER 12.8 was significantly degraded from the baseline IEER 13.9. The average improvement in measured IEER was 21.7%. Improvement at Fort Irwin (AFI) was 30%, improvement at MCASB was 13%, and improvement at CCAFS was 22%. Reduction in energy use averaged 25%. Statistical confidence tests indicate a 96.5% (Anova) and 99.7% (t-Test) probability that the difference between benchmark and test data is real and not due to randomness. A live demonstration via conference call was held to brief ESCO points of contact (Southern Company Energy Services, EMCOR, FPL Energy Services, and NORESCO) on these results.

Table 5. Energy Efficiency Comparison and Savings of Optimized Operation with Test Period Benchmark.

ENERGY EFFICIENCY - Test versus Benchmark

	Site	CCAFS	MCASB	AFI-NTC	**Average**
IEER	Factory Rated	13.2	11.2	10.7	**11.7**
	Baseline (2014)	13.9	11.8	9.5	**11.7**
	Benchmark (2016)	12.8	11.9	9.8	**11.5**
	Optimized	15.5	13.4	12.8	**13.9**
Results	Point Increase	2.7	1.6	3.0	**2.4**
	Efficiency Gain	22%	13%	30%	**21.7%**
	Energy Savings	30%	24%	22%	**25.2%**
Stats	*Confidence Anova*	*0.997*	*0.998*	*0.965*	***0.965***
	Confidence t-Test	*0.99886*	*0.99997*	*0.99878*	***0.9988***

6.1.2 Maintain or Improve Facility Indoor Air Quality (IAQ)

Overall, indoor air quality and thermal comfort was improved or unchanged. Temperature, relative humidity (RH) and carbon dioxide (CO_2) data was collected in the zones served by the demonstration DX units to establish a performance baseline. Data collection continued during EER Optimizer use, providing a basis for comparison between "before" and "after". A comfort level metric was computed via predicted mean vote (PMV) analysis. The PMV is the average comfort vote, using a seven-point thermal sensation scale from cold (-3) to hot (+3). Zero is the ideal value, representing thermal neutrality. The comfort zone is defined by the combinations of the six key factors for thermal comfort for which the PMV is within the recommended limits (-0.5<PMV<+0.5). Using PMV and ASHRAE Standard 55, the percent of people dissatisfied with the thermal comfort conditions was predicted.

<u>CCAFS</u>

Temperature, humidity, number of people dissatisfied, and PMV were significantly improved in the test data set relative to the baseline data as shown in Table 5. There was no change in ventilation level, which was adequate 100% of the time. Temperature was 1.1 degrees-F cooler, corresponding to the aforementioned change in set point. Relative humidity was slightly improved on average. Temperature and humidity were more tightly controlled relative to the baseline period, as indicated by the lower 90th percentile ±1.28σ values in the table.

Table 6. Indoor Air Quality Analysis Values for CCAFS.

CCAFS Indoor Comfort	Data Period	Baseline 2015: Aug 8 - Sep 7 Percent of Hours	Baseline 2015: Aug 8 - Sep 7 Cumulative Hours	EER Optimizer 2016: Aug 8 - Sep 7 Percent of Hours	EER Optimizer 2016: Aug 8 - Sep 7 Cumulative Hours
Temperature	Warm	10.4%	65.4	0.2%	1.2
	Cool	0.0%	0.0	0.0%	0.0
Humidity	Humid	8.1%	60.3	0.0%	0.0
	Dry	0.0%	0.0	0.0%	0.0
Ventilation	Adequate	100.0%	743.8	100.0%	629.0
	CO_2 Avg/Max PPM	437	668	445	679
Comfort	People Dissatisifed	10.4%	65.5	0.2%	1.2
	In Comfort Zone	90.8%	675.2	99.8%	627.8
	Total Data Period	100.0%	743.8	100.0%	629.0

CCAFS Indoor Conditions	Data Period	**Baseline 2015**	**EER Opti 2016**
Temperature [F]	Median	74.2	73.1
	90th ±1.28σ	2.1	0.8
Humidity [%rh]	Median	51.0	49.4
	90th ±1.28σ	8.3	4.4
CO_2 [ppm]	Median	416	414
	90th ±1.28σ	64	79
Comfort [PMV]	Median	0.29	0.14
	90th ±1.28σ	0.33	0.11

PMV Scale
+3 hot
+2 warm
+1 slightly warm
0 neutral
-1 slightly cool
-2 cool
-3 cold

MCASB

While there was no significant change in humidity or ventilation for the test period relative to the baseline data, space temperature was about 2 degrees-F warmer during the test period much of the time. The warmer temperatures on average are accounted for by the increase in space set point from 73F to 75F to comply with energy management policy. Because of the wide BAS control dead band and slow unit response, space temperature was more often pushed beyond the ASHRAE comfort zone limit, as can be seen in the chart in section 5.6.4.

Table 7. Indoor Air Quality Analysis Values for MCASB.

MCASB Indoor Comfort	Data Period	Percent of Hours — **Baseline 2015: Aug 8 - Sep 7**	Cumulative Hours — **Baseline 2015: Aug 8 - Sep 7**	Percent of Hours — **EER Optimizer 2016: Aug 8 - Sep 7**	Cumulative Hours — **EER Optimizer 2016: Aug 8 - Sep 7**
Temperature	Warm	11.1%	82.7	31.6%	234.8
	Cool	0.0%	0.0	0.0%	0.0
Humidity	Humid	0.4%	2.9	0.4%	2.7
	Dry	0.0%	0.0	0.0%	0.0
Ventilation	Adequate	100.0%	744.0	100.0%	744.0
	CO_2 Avg/Max PPM	486	691	473	615
Comfort	People Dissatisifed	11.1%	82.8	31.7%	235.6
	In Comfort Zone	84.3%	627.5	58.8%	437.5
	Total Data Period	100.0%	744.0	100.0%	744.0

MCASB Indoor Conditions	Data Period	**Baseline 2015**	**EER Opti 2016**	**PMV Scale**
Temperature [F]	Median	73.6	75.3	+3 hot
	90^{th} $\pm 1.28\sigma$	2.9	2.9	+2 warm
Humidity [%rh]	Median	50.7	51.4	+1 slightly warm
	90^{th} $\pm 1.28\sigma$	5.1	3.8	0 neutral
CO_2 [ppm]	Median	486	441	-1 slightly cool
	90^{th} $\pm 1.28\sigma$	50	47	-2 cool
Comfort [PMV]	Median	0.30	0.44	-3 cold
	90^{th} $\pm 1.28\sigma$	0.39	0.39	

Fort Irwin (AFI)

Temperature control was improved in the test period relative to the baseline period, with the percentage of hours classified as “warm” dropping from 65% to 10% as shown in Table 6. Although there was no change in setpoint, median temperature dropped from 80.4F to 74.2F. Building 606 is small and has an exposed metal-frame metal roof. The building’s low thermal mass and insulation level present a dynamically challenging load to conventional air conditioner controllers because space temperature rises quickly when the compressors cycle off. There was no significant change in humidity or ventilation. Time in the comfort zone was not improved because the extremely dry conditions were below the comfort zone limit most of the time, as can be seen in the chart in section 5.6.4. Temperature was more tightly controlled relative to the baseline period, as indicated by the lower 90^{th} percentile $\pm 1.28\sigma$ value in the table.

Table 8. Indoor Air Quality Analysis Values for Fort Irwin (AFI).

Fort Irwin Indoor Comfort	Data Period	Baseline 2015: June 4 - 30 Percent of Hours	Baseline 2015: June 4 - 30 Cumulative Hours	EER Optimizer 2016: June 4 - 30 Percent of Hours	EER Optimizer 2016: June 4 - 30 Cumulative Hours
Temperature	Warm	65.2%	409.9	10.1%	63.5
	Cool	1.5%	9.4	0.1%	0.0
Humidity	Humid	0.0%	0.0	0.0%	0.0
	Dry	96.0%	621.9	97.2%	629.6
Ventilation	Adequate	100.0%	648.0	100.0%	648.0
	CO_2 Avg/Max PPM	400	1098	418	1562
Comfort	People Dissatisifed	66.7%	409.9	10.2%	64.3
	In Comfort Zone	3.6%	23.4	2.6%	16.6
	Total Data Period	100.0%	648.0	100.0%	648.0

Fort Irwin Indoor Conditions	Data Period	Baseline 2015	EER Opti 2016
Temperature [F]	Median	80.4	74.2
	90th $\pm 1.28\sigma$	5.0	2.8
Humidity [%rh]	Median	19.0	24.8
	90th $\pm 1.28\sigma$	12.2	9.0
CO_2 [ppm]	Median	396	397
	90th $\pm 1.28\sigma$	20	49
Comfort [PMV]	Median	0.86	0.15
	90th $\pm 1.28\sigma$	0.60	0.34

PMV Scale
+3 hot
+2 warm
+1 slightly warm
0 neutral
-1 slightly cool
-2 cool
-3 cold

6.1.3 Demonstrate Cost Effectiveness of EER Optimizer Technology

Energy savings values shown in section 6.1.1 show a reduction in normalized energy usage averaging 28% among the three demonstration sites. Reduction at Fort Irwin (AFI) was 30%, reduction at MCASB was 24%, and reduction at CCAFS was 30% relative to baseline energy consumption. The electric usage of each unit is shown in the table below; note MCASB usage is over twice that of AFI and CCAFS because the air conditioner unit is twice as large: 20 tons at MCASB versus 12½ tons at AFI and 8¼ tons at CCAFS. Payback period averages 4.8 years and annual return on investment averages 22% for the demonstration units.

Table 9. Energy Savings and Life Cycle Cost Values from the Three Demonstration Sites.

LIFE-CYCLE COST - Test Units

Site	Electric 2016	Energy Saved kWh	Energy Saved Annual	Economics Payback	Economics Annual ROI
MCASB (SC)	$4,495	13,972	$1,397	3.2	31%
AFI-NTC (CA)	$1,783	5,551	$777	5.8	17%
CCAFS (FL)	$1,944	5,998	$840	5.4	19%

Economics cost basis is $4,538 as a factory installed system.

There is a wide variation in cost effectiveness across the three demonstration sites, payback period ranges from 3.2 to 5.8 years. In general, larger units having more energy usage will provide more energy savings. Because the cost of the technology is insensitive to equipment size, it follows that more energy savings at the same cost will result in better project economics. Installation of the technology on larger units gives a shorter the payback period, along with higher return on investment (ROI) and savings to investment ratio (SIR). Similarly, higher cooling loads, longer cooling seasons, and/or higher outdoor temperatures tend to provide more energy savings and better project economics. A secondary savings factor is load profile: cooling load that is steady over the day will provide more savings than a load that rapidly rises to a peak at mid-day and then quickly subsides by late afternoon.

6.1.4 Maintain or Improve Reliability of the AC unit

Repair needs of the demonstration units were compared between the baseline, transition, and test periods. There was a reduction in the level and severity of unplanned and/or emergency repairs, from baseline season to test season. The EER Optimizer system allowed project engineers to identify performance issues sooner and prevent more severe failures. The types of service actions needed in the test period had a lower cost associated with them, indicating that the 57% average reduction in total service costs is at least partially attributable to the EER Optimizer technology. The demonstration units were continuously functional and comfort conditions were maintained at all times during the demonstration, except when powered down for service.

Table 10. Maintenance Needs Comparison of Test Period versus Baseline Period.

MAINTENANCE COMPARISON

	BASELINE PERIOD COSTS			TEST PERIOD COSTS			DELTA
Site	Labor	Refrigerant	**Total**	Labor	Refrigerant	**Total**	Total
MCASB (SC)	$1,575	351	**1,926**	$518	0	**518**	-1408
AFI-NTC (CA)	810	0	**810**	270	0	**270**	-540
CCAFS (FL)	765	71	**836**	540	33	**573**	-263

Labor cost basis $90/hr, R22 cost basis $39.27/lb, R410A cost basis $10.56/lb,

6.1.5 Manageability Using Existing Facility HVAC Staff & Resources

At each demonstration site during the transition period cooling season 2015, a presentation and technology walk-through was held for the HVAC shop supervisor and technicians assigned to work on DX equipment. The following cooling season 2016, a follow up technology review and Q&A session was held with the Facility Manager, shop supervisor, subject matter expert, and technicians to address any concerns and solicit feedback. HVAC technicians at all three demonstration sites agreed the technology can be serviced and maintained with existing staff. Some technicians stated and most others agreed that the remote fault detection & diagnostics feature of the EER Optimizer system is a key benefit for them.

Advantek engineers assisted and trained staff at the demonstration sites on principles and use of EER Optimizer, and were on-call for consultation if questions arose during O&M of demonstration units.

Demonstration units with onboard EER Optimizer were fully instrumented for Advantek to monitor real-time operation and conditioned space parameters and quickly identify O&M anomalies. We set up a quick response system with a base HVAC contractor for dealing with needed maintenance and repair of demonstration units.

6.1.6 Reliability of AC Unit Relative to Reliability of Baseline Unit

The reliability of the demonstration equipment is largely related to the initial system design, including unit sizing, ductwork, and controls; the operating environment, maintenance practices, occupant interventions, as well as manufacturer-determined robustness of technology. To evaluate reliability, we qualitatively assessed reliability of the baseline demonstration units using maintenance data collected prior to using EER Optimizer being installed. The service log entries from the three demonstration units are summarized below.

<u>MCASB</u>

Overall, it appears this unit during the test period was as or more reliable than during the baseline and transition periods. The demonstration unit was originally installed in 2003 and is nearing the end of its service life. Maintenance needs during the baseline and transition periods (2014 and 2015) included replacement of a condenser fan motor, repairing a leaking Schrader fitting, replacement of compressor, replacement of both compressor contactors, and replacement of a leaking low pressure switch; these are typical expected repair items for a unit of this age and condition. Maintenance needs during the test period were reduced overall, however, there were new service needs related to the technology. Test period maintenance included resetting the condenser fan drive when it tripped (3 occurrences), tightening and realigning a fan mount that was vibrating at low speed because it was not properly installed when the fan motor was previously replaced, and cleaning the condenser coil as per EER Optimizer diagnostics.

<u>Fort Irwin</u>

Overall, it appears this unit during the test period was as reliable as during the baseline and transition periods. The demonstration air conditioner was installed in 2010 and suffered from lack of maintenance because the unit was not on the HVAC shop’s PM list; reportedly the omission was the result of an oversight. Maintenance needs during the baseline and transition periods (2014 and 2015) included correcting / repairing economizer control wiring, stage-2 compressor wiring, compressor case heater wiring, and reversing valve wiring; replacement of a compressor, and replacement of the heat pump control board. Maintenance needs during the test period were reduced overall, however, there were new service needs related to the technology. The blower belt needed replacement because of rapid wear due to the blower drive settings, and there were continued issues with the heat pump reversing valve control that ultimately resulted in a compressor replacement. For a more certain solution, the reversing valves were then connected directly to the wall thermostat for switch between cooling and heating mode, to bypass the recurring and seemingly unsolvable problem with the Carrier factory controls.

CCAFS

Overall, it appears this unit during the test period was as reliable as during the baseline and transition periods. The air conditioner was installed in 2012 and most components are in good condition. The unit is located 4,000 feet from the Atlantic Ocean, so salt corrosion of the condenser coil, the compressor contactors and other electrical components is the cause of most maintenance issues with this unit. Maintenance needs during the baseline and transition periods (2014 and 2015) included replacement of the fan relay, replacement of both compressor contactors and C1 contactor twice, repairing a fitting leak & recharge of circuit 2, replacement of a bad high pressure switch, and replacement of corroded heat relay. Maintenance needs during the test period were slightly less overall, however, there were new service needs related to the technology. Test period maintenance included resetting the condenser fan drive when it tripped (2 occurrences), cleaning and coating the condenser coil as per EER Optimizer diagnostics, a second contactor replacement, and repair of a leak in circuit 1.

6.1.7 User Satisfaction

Occupants at the demonstration sites were surveyed regarding their perceived performance of the air conditioning system using a Likert-type survey instrument. The survey was designed to measure changes in satisfaction with the perceived thermal and ventilation comfort provided by the subject technology. The survey questions and response scales are presented in section 5.5 and repeated below for convenience. See Appendix E for response data. There was a 0.20 increase in calibration responses from baseline to test at AFI and CCAFS; survey results were adjusted accordingly. There was a consensus that energy was being used more efficiently.

Overall, the survey responses were more positive for the test period than they were for the baseline period. The largest improvement was at Fort Irwin (AFI), presumably because of the cooler and more consistent temperature and improved air circulation provided by the EER Optimizer technology. This was reflected by the improved responses to all questions. Most of the improvement at CCAFS was to questions 3 and 5 indicating improved ventilation air flow. There was no significant improvement in the MCASB responses; however, there was complete staff turnover between the baseline and the test periods and responses were mostly neutral.

Table 11. Occupant Comfort Perception Survey Results.

OCCUPANT SURVEY RESULTS

	Average Survey Response		
Site	Baseline	Test	**Delta**
MCASB (SC)	2.83	2.96	**0.13**
AFI-NTC (CA)	2.47	3.23	**0.77**
CCAFS (FL)	2.80	3.27	**0.47**

Response scale 1 = worst, 5=best

ANONYMOUS AIR CONDITIONING SURVEY

Scale for questions 1, 2 and 3.   1-very unsatisfied   2-unsatisfied   3-neutral   4-satisfied   5-very satisfied

1. How satisfied are you with the comfort of your office furnishings (chair, desk, computer, equipment, etc.)? [note: calibration question]
2. How satisfied are you with the temperature in your workspace?
3. How satisfied are you with the air quality in your workspace (i.e. stuffy/stale air, cleanliness, odors)?

Scale for question 4 and 5.   1-interferes   2-somewhat interferes   3-neither   4-somewhat enhances   5-enhances

4. Does your thermal comfort in your workspace interfere with or enhance your ability to get your job done?
5. Does the air quality in your workspace interfere with or enhance your ability to get your job done?

Scale for question 6.   1-inefficient   2-somewhat inefficient   3-average   4-somewhat efficient   5-efficient

6. Considering energy use, how efficiently is this building performing in your opinion?

Table 12. Work Log Summaries of Event-based Maintenance Performed on DX Units Fitted with EER Optimizer Onboard Technology, One Unit Each at CCAFS, MCASB, and Fort Irwin.

MCASB Bldg 1283 RT-2 Work Log Summary

Dates	Phase	Total Hours	Work Done	Refrigerant Added
2014	Baseline	17.5	Replace fan motor, fix leaking Schraeder fitting, filter change, replace compressor	8 lbs - 15 oz
2015	Transition	4.5	Replace C1 and C2 contactors, replace leaking low pressure switch, filter change	3 lbs - 2.2 oz
2016	Test	5.75	fan drive trip reset (3x), fix fan mount, clean coil, filter change	0

Fort Irwin Bldg 606 AC Work Log Summary

Dates	Phase	Total Hours	Work Done	Refrigerant Added
2014	Baseline	9	Fix economizer control wiring, fix stage-2 compressor wiring, fix comp heater wiring, fix reversing valve wiring, filter change	0
2015	Transition	13.5	Replace compressor, replace heat pump control board, filter change	14 lbs - 15 oz (Full charge)
2016	Test	3	Replace fan belt, filter change, wire reversing valve direct to thermostat	0

CCAFS-NOTU Hangar Y EDL RTU Work Log Summary

Dates	Phase	Total Hours	Work Done	Refrigerant Added
2014	Baseline	8.5	Replace fan relay, replace C1 contactor, filter change, fix leak & charge circuit 2	6 lbs - 11 oz
2015	Transition	7	replace C2 contactor, filter change, high pressure trip - replace pressure switch, charge C1, replace heat relay	2 lbs - 8.5 oz
2016	Test	6	fan drive trip reset (2x) , replace C2 contactor, clean coil, filter change, fix leak and charge circuit 1	3 lbs - 1.9 oz

6.2 PERFORMANCE OBJECTIVES FOR PORTABLE TECHNOLOGY

6.2.1 Increase AC Units Energy Efficiency

Overall across the three DoD installations included in the demonstration, the energy efficiency of the 30 tested DX HVAC units was measured to have deteriorated by 35% from the factory IEER rating using the portable EER Optimizer (*i*-Optimize) unit. Values in the table below are the totals and averages from the data presented in charts in section 5.6.5 and provided in Appendix C. Average unit age was 10.6 years. Refrigerant loss averaged 17% and totaled 104 lbs, while correcting under / over charge was estimated to provide energy savings of 10%. Partial restoration of energy efficiency via targeted servicing indicated by the portable EER Optimizer unit fault detection & diagnostics, which were deemed cost effective, including coil cleaning, repairs, and correcting refrigerant charge provided energy savings averaging 22% including the refrigerant charge corrections.

Table 13. Portable unit energy efficiency and refrigerant charge results summary.

SUMMARY OF PORTABLE UNIT RESULTS

	Energy Efficiency			Refrigerant	
Site	Age	Loss	Savings	Low lbs	%-Low
MCASB (SC)	13.3	42%	26%	-19.0	-18%
AFI-NTC (CA)	7.8	25%	19%	-44.7	-16%
CCAFS (FL)	10.7	39%	22%	-40.4	-18%
Mean	10.6	35%	22%	-104.1	-17%

6.2.2 Demonstrate Cost Effectiveness of EER Optimizer Technology

Annual energy savings estimates were computed using the measured IEER improvement of the demonstration DX units, the site cooling degree-days, and the site total cost per kWh rate. Implementation costs include the *i*-Optimize portable unit at $3,000, about 8 hours/year labor on average per HVAC unit, and approximately $1,000 parts and $550 refrigerant at each site.

Average implementation cost per site for 10 packaged HVAC units was $11,748, or $102 to $188 per nominal ton. Annual predicted energy savings ranged from $11,310 to $26,573 per year for the 10 units evaluated, which is $181 to $231 savings per nominal ton per year. Economics of the *i-Optimize* technology and subsequent equipment servicing produced payback periods ranging from 0.4 to 1.1 years overall, with savings-to-investment ratio (SIR) ranging from 1.0 to 2.4 for the groups of 10 packaged HVAC units at the three DoD installations.

CCAFS experienced the largest savings, due to the combination of larger ton unit sizes combined with greater potential for improvement. Accordingly, payback period was the shortest at 0.4 year and savings to investment ratio was the highest at 2.4.

Table 14. Portable Unit Energy Savings and Economics Results Summary.

ENERGY

Site	CDD 2016	Tons Total	Energy Used kWh "before"	"after"	kWh %-savings
MCASB (SC)	2851	63	418,316	305,215	27%
AFI-NTC (CA)	2788	150	746,216	609,029	18%
CCAFS (FL)	3588	115	857,902	668,097	22%

LIFE-CYCLE COST

Site	"Before" Cost	Energy Saved kWh	Energy Saved Annual	Economics Payback	Economics SIR
MCASB (SC)	$41,832	113,101	$11,310	1.1	1.0
AFI-NTC (CA)	$74,622	137,187	$19,206	0.6	1.7
CCAFS (FL)	$85,790	189,805	$26,573	0.4	2.4

MCASB

Annual energy savings from servicing the 10 units is predicted to be $11,310 with a payback period of 1.1 years. Economic justification for annual servicing based on energy savings would be justifiable if reliability benefits, reduced potential for unit failure, and potentially extended service life were also considered.

Fort Irwin (AFI)

Annual energy savings from servicing the 10 units is predicted to be $19,206 with a payback period of 0.6 years. Annual performance based maintenance would be cost effective and the savings to investment ratio of 1.7 could meet ESCO performance contract and ESIP funding thresholds.

CCAFS

Annual energy savings from servicing the 10 units is predicted to be $26,573 with a payback period of 0.4 years. Annual performance based maintenance would be cost effective and the savings to investment ratio of 2.4 is well above ESCO performance contract and ESIP funding thresholds.

A white paper summarizing the results of the portable demonstration was shared with ESCO points of contact (Southern Company Energy Services, EMCOR, FPL Energy Services, and NORESCO) with a follow up phone discussion. All were interested in the technology and intend to look for application opportunities as an energy conservation measure.

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7.0 COST ASSESSMENT

This section provides cost information so that an engineering professional can reasonably estimate costs for implementation at a given site. Discussion of the cost benefit of the technology is provided in sections 6.1.3 and 6.2.2.

7.1 COST MODEL FOR ONBOARD SYSTEM

Estimates are listed for each cost element as described in the table below. Equipment includes incremental cost of the EER Optimizer control unit and all sensors, not the air conditioner package unit. Installation costs for retrofit of an existing unit are considerably higher than a factory retrofit. The need for a temporary cooling unit at the site for use while equipment is being installed will depend on the weather and cooling load at the time of the project, and is at the discretion of the facility manager. Estimation of annual energy savings requires input data including electric rates, geographic location, building usage, and cooling load. If the current cooling energy usage of an existing system is known, energy savings can be estimated at 25 to 28% as discussed in section 6.1.1. The range of measured savings among the three demonstration sites was 24% to 30%. It is recommended that Advantek Consulting Engineering be contacted to perform a Rooftop Unit Comparison Calculation (RTUCC) hourly energy usage model to obtain an accurate dollar savings prediction for a specific installation. Maintenance savings is the average of the tracked differential between baseline maintenance costs versus maintenance costs during the test period. Turnover is the cost for a training session for the Facility Manager, Subject Matter Expert (SME), HVAC Shop Supervisor and Technicians (factory cost includes travel to site). Remote monitoring of DX unit performance and diagnostics includes weekly interpretation of operating parameter trends, and forwarding fault detection alerts and alarms to appropriate facility and/or maintenance personnel as they occur.

Table 15. Cost Model for Application of Onboard Technology to New or Existing DX Package Units.

COST MODEL FOR ONBOARD EER OPTIMIZER TECHNOLOGY

Cost Element	Data Collected During Demonstration	Factory New Unit	Retrofit Existing Unit
EQUIPMENT - Capital cost to purchase technology product and components	Paid invoices from vendors & suppliers. This is incremental cost of technology, does not include air conditioner package unit cost.	$4,689	$4,689
INSTALLATION - Labor and Materials	Labor & materials costs provided by subcontractors and accepted by prime, does not include prime / general contractor fees and markup	$3,368	$11,688
TEMPORARY HVAC - service during unit downtime	IF NEEDED depending on cooling load and time of year, service & equipment costs provided by subcontractors and accepted by prime, oes not include prime / general contractor markup	$420	$640
ENERGY SAVINGS - Facility annual operational cost differential	Costs assigned to specific HVAC units being modified, both before & after modifications, including energy and IAQ.	Depends on Unit Size and Climate	Depends on Size, Load and Climate
MAINTENANCE SAVINGS - Maintenance & servicing annual cost differential	Costs determined by facility maintenance managers for before & after modification, and for HVAC staff costs for training and use of EER Optimizer	$737	$737
TURNOVER - Training and monthly monitoring costs	Costs associated with Advantek providing training to maintenance & operational personnel at facility to maintain equipment, and remote monitoring, alerts and alarms	$570 + $80/mo	$235 + $80/mo

7.2 COST MODEL FOR PORTABLE UNIT

Estimates are listed for each cost element as described in the table below. Equipment includes the *i*-Optimize portable unit and a set of clamp-on sensors. Usage is the cost for two performance checks per year per DX unit plus a labor & small parts allowance based on an average of the amounts expended for servicing 30 demonstration units as indicated by *i*-Optimize fault detection & diagnostics. Estimation of annual energy savings requires input data including electric rates, geographic location, building usage, and cooling load. If the current energy usage of a DX unit is known, energy savings can be estimated at 22% as discussed in section 6.2.1. The range of measured savings among the 30 DX units was 4% to 40%. It is recommended that Advantek Consulting Engineering be contacted to perform an RTUCC hourly energy usage model to obtain an accurate dollar savings prediction for a specific installation. Maintenance savings is based on the tracked reduction of needed repairs. Turnover is the cost of a training session for the Facility Manager, SME, HVAC Shop Supervisor and Technicians.

Table 16. Cost Model for Application of Portable i-Optimze Technology.

COST MODEL FOR PORTABLE EER OPTIMIZER TECHNOLOGY

Cost Element	Data Collected During Demonstration	Estimated Cost
EQUIPMENT - Capital cost to purchase technology product	Paid invoices from vendors & suppliers	$3,000
USAGE - Annual Labor and Materials per DX Unit	Labor & materials costs by subcontractors and accepted by prime, does not include prime / general contractor fees and markup. Includes technician time, refrigerant, small parts.	$1,175
ENERGY SAVINGS - Facility annual operational cost differential	Costs assigned to specific HVAC units being modified, both before & after modifications, including energy and IAQ	Depends on Tons, Load and Climate
MAINTENANCE SAVINGS - Annual maintenance cost differential per DX unit	Costs determined by facility maintenance managers for before & after modification, and for HVAC staff costs for training and use of EER Optimizer, both handheld & onboard versions	$438
TURNOVER - Training	Costs associated with Advantek providing training to maintenance & operational personnel at facility to use handheld version and maintain equipment	$435

7.3 ECONOMIC DRIVERS

The costs of utilizing the technology along with electric rates, and energy and maintenance savings drive the economics and determine whether application at a particular building is justifiable via economics alone. Costs as listed in section 7.2 are estimates based on data collected from demonstration at three military installations. At the time of the demonstration, the technology was a beta-stage product with higher costs than the fully commercialized system. Costs are projected to come down as market penetration increases and utilization becomes more widespread. Electric rates among the demonstration sites ranged from 0.06 to 0.14 $/kWh and vary widely among DoD installations enough to strongly affect project economics.

Energy savings has a number of drivers, including air conditioner unit size, total capacity tonnage and baseline energy efficiency level; building cooling load, usage and load profile; and geographic location and climate. The applicable capacity range of DX Air conditioners for this technology is 10 to 100 tons (120,000 to 1,200,000 Btuh). For both the onboard and portable versions, larger units having more energy usage will provide more energy savings. Because cost of both versions of the technology are insensitive to equipment size, it follows that more energy savings will result in better project economics. Utilization of the technology on larger units gives a shorter payback period, along with higher return on investment (ROI) and savings to investment ratio (SIR). Similarly, higher cooling loads and longer cooling seasons tend to provide more energy savings and better project economics. A secondary savings factor is load profile: cooling load that is steady over the day will provide more savings than a load that rapidly rises to a peak at mid-day and then quickly subsides by late afternoon and is minimal overnight.

Breakpoint equipment size minimums listed as nominal unit tons needed to achieve the desired project economic criterion are shown in the tables below. The top table gives sizes for a factory installed system, and the bottom table gives sizes for a field installed retrofit based on the demonstration test results from the three demonstration site locations.

Table 17. Equipment Size Breakpoints to Achieve Desired Project Economic Criteria for Onboard System.

ECONOMICS - Factory Installed System

Site	Savings per Ton	Tons-size for Payback 6 years	Tons-size for Payback 10 years	Tons-size for SIR 1.5	Tons-size for SIR 2.0
South Carolina	$67	11	7	8	11
California	$62	12	7	9	12
Florida	$104	7	4	5	7

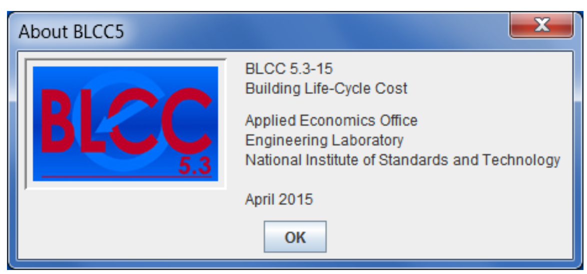
SIR based on 12-year equipment life and $4,538 incremental cost.

ECONOMICS - Field Installed Retrofit

Site	Savings per Ton	Tons-size for Payback 6 years	Tons-size for Payback 10 years	Tons-size for SIR 1.5	Tons-size for SIR 2.0
South Carolina	$67	40	24	36	48
California	$62	43	26	39	52
Florida	$104	26	16	23	31

SIR based on 10-year equipment life and $16,226 retrofit project cost.

7.4 COST ANALYSIS AND COMPARISON



Estimates for the costs of the technology when implemented operationally were input for economic analysis using Building Life-Cycle Cost version 5.3-15, which outputs life-cycle savings, savings to investment ratio, adjusted internal rate of return, and payback period. A study period of 10 years was used, which is the lower end of the 10 to 15 years that typical DX air conditioning systems are kept in service, and the typical length of an ESPC or UESC performance contract along with 0.12 $/kWh and DOE energy cost escalation rates. To provide a useful example, the analyses were performed for a hypothetical site with the average cooling degree-days and cooling load of the three demonstration sites as listed in the tables below.

Table 18. Life-cycle Cost Analysis Parameters for Factory Installed Onboard System.

BLCC ECONOMIC ANALYSIS - EER Optimizer Factory Install

PROJECT		
Discounting Convention	End of Year	
Analysis	Current (includes inflation)	
Discount Rate	3.10%	
Base Date	January-18	
Occupancy from Base	0 years 0 months	
Length of Study	10 years 0 months	
ALTERNATIVES	EER Optimizer Factory	Existing Unit
Cooling Degree Days	3076	3076
AC Unit Size	20 Tons	20 Tons
Efficiency IEER	13.9	11.5
Load FLEOH	2461	2461
Savings	26.6%	-
Annual Consumption kWh	37,788	51,495
Investment Initial Cost	8,057	0
Annual O&M Cost	453	1191
Annual FD&D Monitoring	880	-
BLCC LIFE CYCLE RESULTS		
Energy Savings	$12,317	
O&M Net Savings	$493	
PV Life Cycle Cost Savings	$4,753	
Savings to Investment SIR	1.59	
AIRR	8.00%	
Payback Occurs in Year	6	

A commonly used air conditioner unit size of 20 tons was chosen for the factory installed analysis; note the economic calculations are strongly dependent on unit size. For example, installation on a 30-ton unit will provide roughly 50% better economic values, and likewise installation of a 10-ton unit will provide roughly 50% worse economic values. Economic parameters are also a function of climate and the building cooling load profile. The factory installed example in the table has a payback period of 6 years and an SIR of 1.59. The BLCC analysis can be duplicated using the values in the tables for use in 'what if' scenarios.

The higher cost of a field retrofit can be justified for larger equipment sizes and/or hot climates and higher cooling loads. A common large unit size of 60 tons was chosen for the field retrofit analysis, giving a payback period of 4 years and an SIR of 2.29. Installation in a milder climate, for example 2000 rather than 3000 cooling degree-days would provide roughly one-third worse economic values; while installation onto a building with a heavier load profile, for example 3600 rather than 2461 full load equivalent operating hours (FLEOH) would provide roughly 50% better economic values. Because of the sensitivity to site specifics, an RTUCC hourly simulation is recommended.

Table 19. Life-cycle Cost Analysis Parameters for Field Retrofit Onboard System.

BLCC ECONOMIC ANALYSIS - EER Optimizer Field Retrofit

PROJECT		
Discounting Convention	End of Year	
Analysis	Current (includes inflation)	
Discount Rate	3.10%	
Base Date	January-18	
Occupancy from Base	0 years 0 months	
Length of Study	10 years 0 months	
ALTERNATIVES	EER Optimizer Field Retrofit	Existing Unit
Cooling Degree Days	3076	3076
AC Unit Size	60 Tons	60 Tons
Efficiency IEER	13.9	11.5
Load FLEOH	2461	2461
Savings	26.6%	-
Annual Consumption kWh	113,364	154,485
Investment Initial Cost	16,377	0
Annual O&M Cost	453	1191
Annual FD&D Monitoring	880	-
BLCC LIFE CYCLE RESULTS		
Energy Savings	$36,950	
O&M Net Savings	$493	
PV Life Cycle Cost Savings	$21,066	
Savings to Investment SIR	2.29	
AIRR	11.99%	
Payback Occurs in Year	4	

The example portable system analysis is based on one *i*-Optimize portable unit being used to support performance based maintenance (PBM) of 10 DX package air-conditioners totaling 109 tons, with replacement of the *i*-Optimize unit 5 years into the 10 year study period. Depending on resources and scheduling, a PBM program may include more or less than 10 air-conditioners per portable unit. Both the estimated performance based maintenance and traditional event-based servicing are carried out by HVAC technicians. In some cases the technicians are from the same organization, and in other cases O&M HVAC shop, base maintenance contractor technicians, and ESCO or outside contractor PBM technicians. In any case, the analysis categorizes PBM costs as part of the technology investment, which is mostly offset by O&M savings.

Table 20. Life-cycle Cost Analysis Parameters for Portable System with Performance Based Maintenance.

BLCC ECONOMIC ANALYSIS - PORTABLE *i*-Optimize 10 unit PMB

PROJECT		
Discounting Convention	End of Year	
Analysis	Current (includes inflation)	
Discount Rate	3.10%	
Base Date	January-18	
Occupancy from Base	0 years 0 months	
Length of Study	10 years 0 months	
ALTERNATIVES	PMB Using i-Optimize	No Change
Cooling Degree Days	3076	3076
AC Units Total Tons	109 Tons (10 Units)	109 Tons (10 Units)
Mean Efficiency IEER	9.4	7.3
Mean Load FLEOH	2461	2461
Mean Savings	22.5%	-
Annual Consumption kWh	340,434	439,357
Investment Cost	6,870	0
Annual OM&R Cost	4,535	11,905
Annual PBM Cost	11,748	-
BLCC LIFE CYCLE RESULTS		
Energy Savings	$88,888	
O&M Savings	$79,725	
PV Life Cycle Cost Savings	$59,182	
Savings to Investment SIR	1.54	
AIRR	7.65%	
Payback Occurs in Year	1	

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8.0 IMPLEMENTATION ISSUES

Information that will aid in the implementation of the technology is explained below.

1. A key lesson learned from implementation of the technology at the demonstration sites centers around the condition of the air conditioner unit(s) selected for field retrofit. It is critical that equipment be well-maintained and in good operating condition. The applicable capacity range of DX Air conditioners for this technology is 10 to 100 tons (120,000 to 1,200,000 Btuh). Units that do not have the original factory compressors are not good candidates for retrofit. If unavoidable, the cost of refurbishing or making repairs to equipment in poor condition should be included in the project economic evaluation.

2. EER Optimizer enhanced RTUs may be a viable and cost effective replacement for aging chilled water cooling systems, especially if reduction of water consumption is desired.

3. Project buy-in from the installation HVAC maintenance shop and/or base maintenance contractor and the contracting officer is essential to successful implementation.

4. Project justification can be based on one or more of the following benefits:
   a. *Continuously optimizes operational parameters to minimize energy costs while improving occupant comfort and productivity.*
   b. *Slows performance deterioration and potentially add years of service life before replacement is needed.*
   c. *Provides a realistic and objective assessment of in-situ equipment operating condition to guide the repair or replace decision process.*
   d. *Detects & diagnoses faults for performing targeted preventive maintenance or supporting performance based maintenance to maximize cost effectiveness.*
   e. *Provides remote connection to the controller to identify issues before they become problematic, or for faster response to an occupant complaint, and to enhance technician productivity.*

5. Cooling load, climate and electric rates are key drivers of project economics. Higher cooling load, longer cooling season, larger equipment size, and higher electric rate tends to mean shorter payback period and higher Adjusted Rate of Return (AROR) and Savings to Investment Ratio (SIR).

6. Factory installation will provide the best project economics. Specified DX package unit(s) are shipped to ClimaTek HVAC LLC from the OEM and then to the project site. Allow 8 weeks in the project schedule for installation, testing and shipping.

7. For full functionality an internet connection will be needed. This can be provided by, in order of preference, (a) facilities LAN, (b) installation VLAN, (c) dedicated WAN-ISP, or (d) self-contained cellular.

8. Field retrofit costs are largely driven by mobilization and travel, so retrofit projects including at least two to four DX systems have an economy of scale and are easier to justify.

9. Unitary equipment older than one year are usually past the warranty period unless an extended warranty was purchased. Installation of the on-board EER Optimizer system requires adding components to the refrigeration circuit, which could result in a factory compressor warranty claim being denied. Typically, the EER Optimizer installer assumes responsibility for compressor a warranty claim if the manufacturer will not. Note that compressor operating temperature will be reduced, and compressors will be protected by the liquid-vapor separator installed upstream of the compressor, tending to reduce compressor stress.

10. Please reference the following peer reviewed publications for additional technical details.

West, Michael and Richard Combes, "Continuous Tuning of Refrigerant Charge to Improve DX Equipment Performance." ASHRAE Transactions, 2017 Winter Meeting.

West, Michael and Richard Combes, "Unitary HVAC Equipment: Performance Optimization Strategy and Field Tests." ASHRAE Transactions, 2016 Winter Meeting.

West, Michael and Richard Combes, "What Owners Need to Know About Rooftop Unit Maintenance." HPAC Engineering, Vol. 86, No. 10, pp. 18-23. October 2014. hpac.com/october-2014-digital-edition#5

West, Michael and Thomas Brooke. "Improvement of IEER Rating and Dehumidification Capability in Unitary DX Equipment." ASHRAE Transactions, 2013 Annual Meeting.

West, Michael and Richard Combes. "Improvement of Integrated Energy Efficiency and Latent Cooling Capability by Refrigeration Cycle Variation with Evaporator Coil Optimization in R-410a Unitary Equipment." ASHRAE Transactions, 2013 Annual Meeting.

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13) Rodriguez, A. *Effect of Refrigerant Charge, Duct Leakage, and Evaporator Air Flow on the High Temperature Performance of Air Conditioners and Heat Pumps*. Texas A&M University, August 1995.

14) Farzad, M. and O'Neal, D.L. *Influence of the Expansion Device on Air-Conditioner System Performance Characteristics under a Range of Charging Conditions*. ASHRAE Transactions Vol.99, part 1. 1993.

15) Hewett, Martha J., Bohac, D.L.; et al. *Measured Energy and Demand Impacts of Efficiency Tune-ups for Small Commercial Cooling Systems*. ACEEE 1992 Summer Study on Energy Efficiency in Buildings, proceedings of, Vol.3. 1992.

16) Neal, L. *Field Experiences with Central Air Conditioners and Heat Pumps*. AEC North Carolina Alternative Energy Corporation, Research Triangle Park. 1990.

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APPENDIX A POINTS OF CONTACT

Point of Contact Name	Organization Name	Phone Email	Role in Project
Mike West	Advantek	321-733-1426 x3 mwest@advantekinc.com	Principal Investigator
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Neil Tisdale	Marine Corps	843-228-6317 belton.tisdale@usmc.mil	Utilities Director, Marine Corps Air Station Beaufort
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APPENDIX B EQUIPMENT CALIBRATION AND DATA QUALITY

B.1 Calibration of Equipment

The data loggers with all sensors connected underwent a week-long bench top break-in and 2-points per sensor calibration verification two weeks before being transported to the demonstration site. Sensors not within the sensor manufacturer's calibration tolerances were returned to the manufacturer for calibration or replacement, or a calibration factor was entered into the data logger setup file, depending on the error as compared to the manufacturer's specified error tolerance.

B.2 Quality Assurance Sampling

Upon installation at the demonstration sites, a quality assurance sampling protocol was implemented for verification of data logger / sensor accuracy as follows:

- By operating the RTU with compressors *off* for one to two hours, all temperatures, pressures, voltages and humidifies were allowed to stabilize at expected common values, which were verified with recently calibrated portable instruments.
- Air velocity, temperature and humidity, static pressure, unit power kW, fan Watts, blower Watts, refrigerant flow rate, receiver mass, and compressor amperages were checked against high-accuracy portable instruments. A record of values from the data logger files versus calibration values was kept in a calibration spreadsheet along with the initial data sampling and used for reference when sensors or data loggers were replaced.
- At approximately one week intervals, extended compressor *off* periods in the data sets were checked for on-going quality assurance sampling. Data accuracy discrepancies were checked onsite with hand-held instrumentation, and suspect sensors were re-calibrated or replaced.

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APPENDIX C DX UNIT NAMEPLATE DATA

MCASB

BUILDING NUMBER	MARK	MAKE	MODEL NUMBER	SERIAL NUMBER	MFR DATE	RATED IEER	NOM TONS
1283	RT-1	TRANE	YCD151C3HOBA	318100688D	May-03	11.5	12½
1283	RT-11	TRANE	YHCO36A3RMA1	317101829L	Apr-03	10.7	3
1283	RT-3	TRANE	YHC092A3RH	317101638L	Apr-03	11.0	7½
1283	RT-4	TRANE	YHC060A3	317101674L	Apr-03	10.2	5
1283	RT-5	TRANE	YHC036A3	3171011765L	Apr-03	10.7	3
1283	RT-6	TRANE	YHC036A3RM	317101603L	Apr-03	10.7	3
1283	RT-7	TRANE	YCD151C3HOBA	318100634D	May-03	11.5	12½
1283	RT-8	TRANE	YCP024F1MOBA	3062LEA1H	Feb-03	12.0	2
1283	RT-9	TRANE	YHC120A3	3171016521	Apr-03	11.3	10
1283	RT-10	TRANE	YSC048A3EMA1	514102022L	Mar-05	10.0	4

FORT IRWIN

BUILDING NUMBER	MARK	MAKE	MODEL NUMBER	SERIAL NUMBER	MFR DATE	RATED IEER	NOM TONS
604		TRANE	WSC120E3R	947100Z97L	Oct-09	13.1	10
308		TRANE	YCH210E360BA	921100202D	May-09	10.0	17½
308		TRANE	YCH300E360BA	905100049D	Feb-09	9.8	25
16		CARRIER	50TCQD14A2A	1012G10295	Feb-12	10.7	12½
127		CARRIER	48HCDD17A7A6A2BOA0	4014P15186	Sep-14	13.0	15
918	RTU-16	TRANE	WCD180B400HA	712100181D	Mar-07	10.0	15
918	RTU-15	TRANE	WCD180B400HA	710101351D	Mar-07	10.0	15
918	RTU-9	TRANE	WSC120A4R0A23	713102094L	Mar-07	13.1	10
918	RTU-5	TRANE	WSC120A4R0A23	713102330L	Mar-07	13.1	10
918	FOOD CT	TRANE	WCD240B4009A	535101292D	Aug-05	9.70	20

CCAFS

BUILDING NUMBER	MARK	MAKE	MODEL NUMBER	SERIAL NUMBER	MFR DATE	RATED IEER	NOM TONS
62630	NONE	TRANE	TCD241C40FCB	6381008660	Sep-06	10.3	20
62630	SOUTH	CARRIER	50TM-012	2206G40709	May-06	11.1	10
62630	NORTH	CARRIER	50TM-012	2206G50701	May-06	11.1	10
55865		TRANE	TCH211C300AB/TFH21C300AB	P46101472D	Dec-99	12.0	17½
81701		TRANE	TCH181C400AA/TFH181C400AA	P46104116D	Dec-99	13.3	15
55893		CARRIER	50TCQD12A285/AOAOAO	3514P72396	Aug-14	11.3	10
49926		TRANE	4TCC3024A100AA	7105KNK9H	Mar-07	13.0	2
49926		TRANE	THC181A 300AA	P46100679D	Nov-99	13.3	15
1115		CARRIER	50HC-D09A 1A5A0A0A0	2610G50598	Jun-10	12.2	8¼
52003		CARRIER	50TC-D08 A3L5A0C0A0	3509G20924	Aug-09	11.7	7½

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APPENDIX D DX UNIT PERFORMANCE DATA

MCASB

					ENERGY EFFICIENCY IEER							
					RATED IEER	MEASURED IEER		% DEGRADED		AFTER SERVICE		
BUILDING NUMBER	MARK	MAKE	MFR DATE	AGE		CIRC 1	CIRC 2	CIRC 1	CIRC 2	CIRC 1	CIRC 2	SAVED
1283	RT-1	TRANE	May-03	13.4	11.5	3.7	9.2	68%	20%	9.1	9.2	30%
1283	RT-11	TRANE	Apr-03	13.5	10.7	5.0		53%		8.4		40%
1283	RT-3	TRANE	Apr-03	13.5	11.0	6.4	7.1	42%	35%	8.6	8.7	22%
1283	RT-4	TRANE	Apr-03	13.5	10.2	6.6		35%		8.0		17%
1283	RT-5	TRANE	Apr-03	13.5	10.7	6.0		44%		8.4		29%
1283	RT-6	TRANE	Apr-03	13.5	10.7	6.0		44%		8.4		29%
1283	RT-7	TRANE	May-03	13.4	11.5	6.5	6.5	43%	44%	9.1	9.2	29%
1283	RT-8	TRANE	Feb-03	13.7	12.0	7.2		40%		9.4		24%
1283	RT-9	TRANE	Apr-03	13.5	11.3	6.5	5.7	42%	50%	8.9	9.0	32%
1283	RT-10	TRANE	Mar-05	11.6	10.0	7.1		29%		8.2		13%
			MEAN	13.3	11.0		6.4		42%		8.8	26%

FORT IRWIN

					ENERGY EFFICIENCY IEER							
					RATED IEER	MEASURED IEER		% DEGRADED		AFTER SERVICE		
BUILDING NUMBER	MARK	MAKE	MFR DATE	AGE		CIRC 1	CIRC 2	CIRC 1	CIRC 2	CIRC 1	CIRC 2	SAVED
604	604	TRANE	Oct-09	7.0	13.1	11.2	11.5	14%	12%	12.0	12.1	6%
308	308S	TRANE	May-09	7.4	10.0	7.4	7.4	26%	26%	9.1	9.2	19%
308	308B	TRANE	Feb-09	7.7	9.8	7.3	7.2	26%	26%	8.9	9.0	19%
16	16	CARRIER	Feb-12	4.7	10.7	9.7	9.7	10%	9%	10.1	10.2	5%
127	127	CARRIER	Sep-14	2.1	13.0	9.7	12.2	26%	6%	12.7	12.8	14%
918	RTU-16	TRANE	Mar-07	9.6	10.0	4.0	7.6	60%	24%	8.9	9.0	36%
918	RTU-15	TRANE	Mar-07	9.6	10.0	7.6	7.6	24%	24%	8.9	9.0	15%
918	RTU-9	TRANE	Mar-07	9.6	13.1	10.0	9.9	24%	24%	11.7	11.8	15%
918	RTU-5	TRANE	Mar-07	9.6	13.1	4.3	10.1	67%	23%	11.7	11.8	39%
918	FOOD CT	TRANE	Aug-05	11.2	9.7	6.9	6.9	29%	28%	8.5	8.6	19%
			MEAN	7.8	11.3		8.4		25%		10.3	19%

CCAFS

					ENERGY EFFICIENCY IEER							
					RATED IEER	MEASURED IEER		% DEGRADED		AFTER SERVICE		
BUILDING NUMBER	MARK	MAKE	MFR DATE	AGE		CIRC 1	CIRC 2	CIRC 1	CIRC 2	CIRC 1	CIRC 2	SAVED
62630	62630	TRANE	Sep-06	10.1	10.3	5.9	6.1	43%	41%	8.2	8.3	27%
62630	62630S	CARRIER	May-06	10.4	11.1	5.7	7.2	49%	36%	8.7	8.8	27%
62630	62630N	CARRIER	May-06	10.4	11.1	6.7	6.8	39%	39%	8.7	8.8	23%
55865	55865	TRANE	Dec-99	16.8	12.0	5.7	5.5	53%	55%	7.9	8.0	30%
81701	81701	TRANE	Dec-99	16.8	13.3	6.2	5.6	53%	58%	8.8	8.9	33%
55893	55893	CARRIER	Aug-14	2.2	11.3	10.2	10.2	10%	10%	10.8	10.9	6%
49926	49926	TRANE	Mar-07	9.6	13.0	9.9		24%		10.5		6%
49926	49926	TRANE	Nov-99	16.9	13.3	6.2	6.1	53%	54%	8.8	8.9	31%
1115	1115	CARRIER	Jun-10	6.3	12.2	10.2	10.2	16%	16%	10.6	10.7	4%
52003	52003	CARRIER	Aug-09	7.2	11.7	5.5	7.5	53%	36%	10.0	10.1	35%
			MEAN	10.7	11.9		7.2		39%		9.3	22%

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APPENDIX E DX UNIT REFRIGERANT CHARGE DATA

MCASB

				REFRIGERANT CHARGE							
				NAMEPLATE LBS		MEASURED LBS		OVER/UNDER LBS		% OVER/UNDER	
BUILDING NUMBER	**MARK**	**MAKE**	**R22 or R410A**	CIRC 1	CIRC 2	CIRC 1	CIRC 2	CIRC 1	CIRC 2	CIRC 1	CIRC 2
1283	RT-1	TRANE	22	15.0	13.8	7.9	17.6	-7.1	3.8	-47%	28%
1283	RT-11	TRANE	22	5.3		3.2		-2.1		-40%	
1283	RT-3	TRANE	22	6.4	6.2	4.4	4.8	-2.0	-1.4	-31%	-23%
1283	RT-4	TRANE	22	8.4		6.6		-1.8		-21%	
1283	RT-5	TRANE	22	5.3		4.6		-0.7		-13%	
1283	RT-6	TRANE	22	5.3		4.6		-0.7		-13%	
1283	RT-7	TRANE	22	15.0	13.8	13.6	12.0	-1.4	-1.8	-9%	-13%
1283	RT-8	TRANE	22	7.3		5.2		-2.1		-29%	
1283	RT-9	TRANE	22	11.0	7.3	11.8	5.4	0.8	-1.9	7%	-26%
1283	RT-10	TRANE	22	3.8		3.2		-0.6		-16%	
				TOTAL LBS	123.9			**TOTAL LBS**	-19.0	**AVG**	-18%

FORT IRWIN

				REFRIGERANT CHARGE							
				NAMEPLATE LBS		MEASURED LBS		OVER/UNDER LBS		% OVER/UNDER	
BUILDING NUMBER	**MARK**	**MAKE**	**R22 or R410A**	CIRC 1	CIRC 2	CIRC 1	CIRC 2	CIRC 1	CIRC 2	CIRC 1	CIRC 2
604	604	TRANE	R410A	9.8	9.3	7.9	8.2	-1.9	-1.1	-19%	-12%
308	308S	TRANE	R410A	21.0	9.8	18.8	9.1	-2.3	-0.7	-11%	-7%
308	308B	TRANE	R410A	18.3	18.3	17.8	17.4	-0.5	-0.9	-3%	-5%
16	16	CARRIER	R410A	14.5	13.5	12.9	12.3	-1.6	-1.3	-11%	-9%
127	127	CARRIER	R410A	17.0	16.4	10.6	16.2	-6.4	-0.2	-38%	-1%
918	RTU-16	TRANE	R22	19.9	9.9	10.5	8.5	-9.4	-1.4	-47%	-14%
918	RTU-15	TRANE	R22	19.9	9.9	17.6	8.9	-2.3	-1.0	-11%	-10%
918	RTU-9	TRANE	R22	7.9	7.9	7.1	6.8	-0.8	-1.1	-10%	-14%
918	RTU-5	TRANE	R22	7.9	7.9	4.0	7.8	-4.0	-0.1	-50%	-1%
918	FOOD CT	TRANE	R22	22.0	21.0	17.7	17.4	-4.3	-3.6	-20%	-17%
				TOTAL LBS	282.0			**TOTAL LBS**	-44.7	**AVG**	-16%

CCAFS

				REFRIGERANT CHARGE							
				NAMEPLATE LBS		MEASURED LBS		OVER/UNDER LBS		% OVER/UNDER	
BUILDING NUMBER	**MARK**	**MAKE**	**R22 or R410A**	CIRC 1	CIRC 2	CIRC 1	CIRC 2	CIRC 1	CIRC 2	CIRC 1	CIRC 2
62630	62630	TRANE	R22	21.3	21.0	14.9	15.3	-6.4	-5.7	-30%	-27%
62630	62630S	CARRIER	R22	8.6	8.5	5.6	7.3	-3.0	-1.2	-34%	-15%
62630	62630N	CARRIER	R22	8.6	8.5	6.6	6.6	-2.0	-1.9	-24%	-23%
55865	55865	TRANE	R22	25.7	12.5	24.8	10.5	-0.9	-2.0	-4%	-16%
81701	81701	TRANE	R22	26.6	10.9	24.3	8.4	-2.3	-2.5	-9%	-23%
55893	55893	CARRIER	R410A	15.1	14.2	12.7	12.0	-2.4	-2.2	-16%	-15%
49926	49926	TRANE	R410A	5.8		5.1		-0.7		-12%	
49926	49926	TRANE	R22	26.6	10.9	24.6	9.3	-2.0	-1.6	-8%	-14%
1115	1115	CARRIER	R410A	9.9	9.9	9.9	9.9	0.0	0.0	0%	0%
52003	52003	CARRIER	R410A	4.4	4.4	2.4	2.8	-2.0	-1.6	-46%	-37%
				TOTAL LBS	253.4			**TOTAL LBS**	-40.4	**AVG**	-18%

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APPENDIX F OCCUPANT SURVEY DATA

See section 5.5 for ANONYMOUS AIR CONDITIONING SURVEY questions and response scale.

CCAFS Question	Baseline 2014 Survey Number					Avg	Test 2016 Survey Number					Avg
	1	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
1	3	3	4	2	2	2.8	3	3	4	2	3	3.0
2	4	4	5	3	2	3.6	4	4	5	4	3	4.0
3	2	3	2	2	3	2.4	3	4	4	3	4	3.6
4	2	3	3	4	3	3.0	3	3	3	3	3	3.0
5	1	3	3	2	3	2.4	3	4	3	3	4	3.4
6	3	3	2	2	3	2.6	3	4	4	4	4	3.8
Averages	2.5	3.2	3.2	2.5	2.7	**2.8**	3.2	3.7	3.8	3.2	3.5	**3.5**

MCASB Question	Baseline 2014 Survey Number				Avg	Test 2016 Survey Number				Avg
	1	**2**	**3**	**4**		**1**	**2**	**3**	**4**	
1	3	3	2	3	2.8	3	2	3	3	2.8
2	2	3	2	2	2.3	3	3	2	3	2.8
3	3	4	3	3	3.3	4	3	3	3	3.3
4	3	3	2	3	2.8	3	2	3	3	2.8
5	3	3	2	3	2.8	3	2	3	3	2.8
6	3	3	4	3	3.3	3	4	3	4	3.5
Averages	2.8	3.2	2.5	2.8	**2.8**	3.2	2.7	2.8	3.2	**3.0**

AFI Question	Baseline 2014 Survey Number					Avg	Test 2016 Survey Number					Avg
	1	**2**	**3**	**4**	**5**		**1**	**2**	**3**	**4**	**5**	
1	2	3	2	3	2	2.4	3	2	2	3	3	2.6
2	3	2	2	2	2	2.2	4	4	4	5	3	4.0
3	2	2	2	2	3	2.2	4	3	4	4	4	3.8
4	3	3	2	3	3	2.8	3	3	4	4	3	3.4
5	2	2	3	2	3	2.4	3	4	3	3	4	3.4
6	3	3	2	3	3	2.8	3	4	3	3	4	3.4
Averages	2.5	2.5	2.2	2.5	2.7	**2.5**	3.3	3.3	3.3	3.7	3.5	**3.4**

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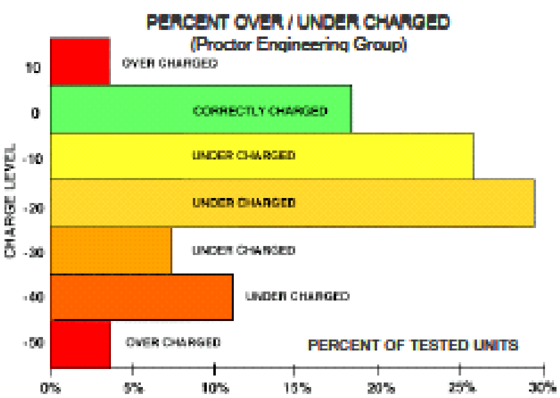
APPENDIX G TECHNOLOGY FACTSHEET

EER Optimizer Technology

The EER Optimizer provides an accurate and practical measurement of the EER of any DX cooling unit, expressed in the standard units of cooling capacity per unit of energy use (Btuh per Watt, MBH per kW, or COP) or as a 4-20mA control signal. Having the actual operating EER is key to improving efficiency, because it provides a realistic assessment of current equipment condition with feedback so operating parameters can be optimized.

Setting and maintaining refrigerant charge level is the most basic of service procedures, yet it is the most error prone.



Manufacturer-specified refrigerant level is often not set or maintained properly, which results in less than rated performance. In addition to leakage, even an adequately charged system will have too much refrigerant for some operating conditions and not enough for others. An air-conditioner's nameplate charge level is necessarily a manufacturer compromise to assure ample capacity/protection under all foreseeable operating conditions in all climates, yet it does not ensure optimal annual energy efficiency. The current refrigerant of choice (R-410a) is a mixture of two refrigerants (50% R-32 and R-125) that have differing thermodynamic properties and thus fractionalize, which further complicates determination and adjustment of the proper refrigerant level.

Maximize Energy Efficiency without having to rely on frequent service calls.

"…the air conditioning system can be performing below its capacity because of poor maintenance and maintain comfort while energy use increases."

"I don't see anyone really checking charge right, most technicians only do a touch method."

"I have even found 8 ounces overcharge on brand new units." [total charge is 5 to 8 pounds]

EER Optimizer technology has been incorporated into a prototype (1) hand-held service technician tool, and (2) on board refrigerant level and fan speed /airflow controller. For the service instrument, the EER measurement is clearly displayed, allowing a technician to immediately appraise the operating efficiency of any unit. The on-board controller continuously seeks to maximize EER via adjusting the coil airflow, refrigerant level, condenser fan speed, and other parameters as needed.

Measure, display, and feedback the actual operating EER of any unit.

Accurate and quick measurement of air-conditioner energy efficiency enables facility managers to economically justify major service or replacement of low-performing equipment. These air-conditioning units would otherwise unknowingly be operated at dismal efficiency levels. Cost is estimated at $1000 for a mass produced on-board controller version, and around $2000 for a commercial instrument.

"In general, service calls and annual tune-ups are not profit makers [for AC service contractors]."

"The bulk of the contractor's profits come from selling replacement parts and from selling a replacement air conditioner when the current unit fails."

"… it would be hard to implement [proper service] under the pressure of having several 'no cool' calls waiting for their arrival."

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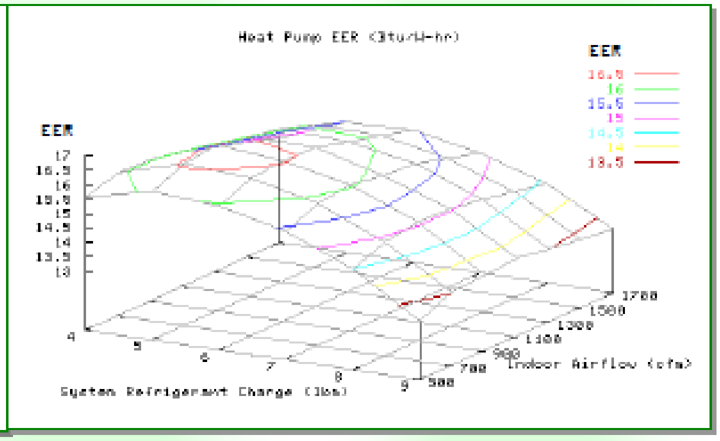
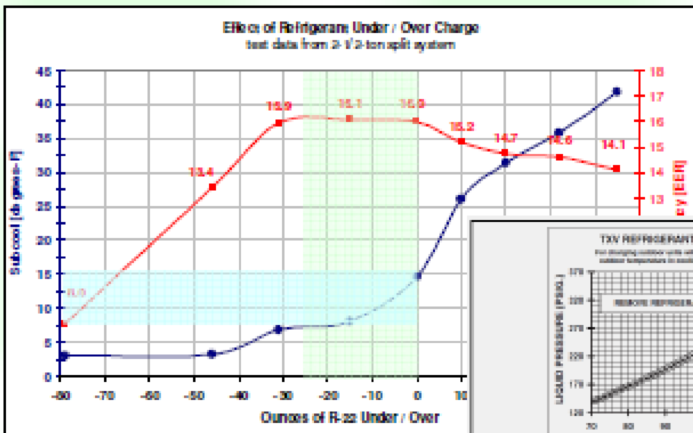
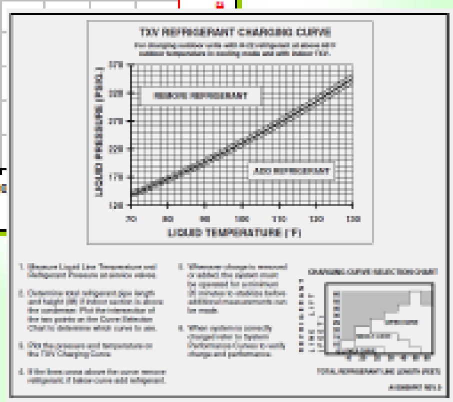
Heat Pump EER varies with Indoor Airflow over the cooling coil. The optimal System Refrigerant Charge in turn varies with Indoor Airflow in order to maximize the operating EER.

Consider a nominal system charge of 7.9 lbm for example: Maximum obtainable EER from the map is 15.0 at 1100 cfm. At low load, adjusting the charge to 4.7 lbm and decreasing coil airflow to 900 cfm increased EER to 16.7 - an 11% improvement at this low-load condition.







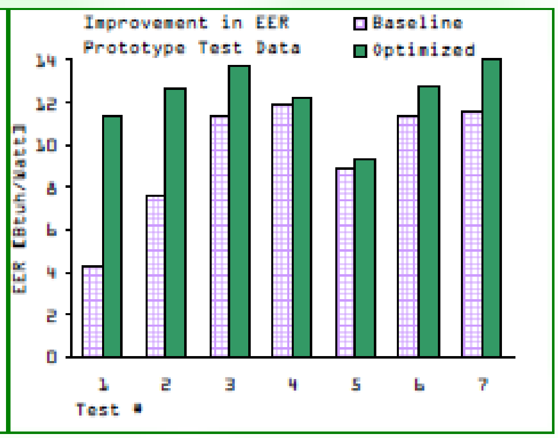
Ideally, technicians use the charging curve charts provided by the equipment manufacturer for each model they service. Followed closely, the charts guide charge adjustment to a nominal level. However, the resulting charge is not necessarily optimal for all operating conditions. The red line in the data chart shows how EER can degrade substantially from just a few ounces of under or over charge.

78% of units tested by Proctor Engineering Group were in the under-charged regime where EER drop-off is exceedingly steep.

[Downey, T. and Proctor, J. *What Can 13,000 Air Conditioners Tell Us?* Proceedings of the ACEEE 2002 Summer Study on Energy Efficiency in Buildings, 1:53-68.

Checks of 4,385 commercial DX units by Proctor Engineering Group indentified 60% of the units needed charge adjustment.

EER Optimizer Test Data demonstrates a significant EER increase averaging 42%. For example Test #6: The optimal charge at 1700 cfm and 84F ambient was 7.9 lbm. As outdoor temperature drops to 76F, airflow was adjusted to 1100 cfm to maximize EER and charge was adjusted to 8.4 lbm to maximize cooling capacity. This is because EER varies with outdoor air inlet temperature at the condenser coil. The required system refrigerant charge in turn varies in order to maximize cooling capacity. Current technology cannot make this adjustment.



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